FAO AGRICULTURAL SERVICES BULLETINS

MANUALS ON SERICULTURE

MULBERRY CULTIVATION
SILKWORM REARING
SILK REELING
NON-MULBERRY SILKS

Reprinted by: CENTRAL SILK BOARD BANGALORE INDIA

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FAO AGRICULTURAL SERVICES BULLETINS

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS ROME

MANUALS ON SERICULTURE

Volume 1 – 15/1 – MULBERRY CULTIVATION
Volume 2 –15/2 –SILKWORM REARING
Volume 3 –15/3 – SILK REELING
Volume 4 – 29 – NON-MULBERRY SILKS

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It is with a sense of satisfaction that the Central Silk Board now presents the reprints of FAO Agricultural Services Bulletin Series, Sericulture Manuals — 1: Mulberry Cultivation; 2: Silkworm Rearing; 3: Silk Reeling, Nos. 15/1, 15/2 and 15/3 and, 4: Non-Mulberry Silks No. 29. These reprints are meant for use by the technical and extension personnel of the Central Silk Board and for educational and reference purposes.

The reprint of the four FAO manuals is the fulfilment of a long-felt need in our country for such authenticated literature on the different aspects of sericulture. The value of these volumes is incalculable to the extension personnel.

This venture has been made possible by the generosity of the Food and Agriculture Organization of the United Nations which has so kindly permitted us to reprint.

We are thankful to them.

BANGALORE,
19th March 1987.

V.BALASUBRAMANIAN
MEMBER-SECRETARY
CENTRAL SILK BOARD
BANGALORE INDIA.

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FOOD AND AGRICULTURE ORGANIZATION
OF THE UNITED NATIONS ROME

Sericulture Manual
1 — Mulberry Cultivation

FAO AGRICULTURAL SERVICES BULLETIN 15/1

sericulture manual
1 — mulberry cultivation

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FOREWORD

Mulberry cultivation is the agricultural part of sericulture which constitutes not only the rearing of silkworms but also silk reeling. Cultivation of mulberry plays a significant role in determining the production cost of cocoons and silk as it is estimated that 60 per cent of the cost of cocoons goes to mulberry.

The technique of cultivating mulberry plants varies in different parts of the world depending upon the climatic conditions as also the soil types. While trees are raised in temperate climates like Japan, mulberry is raised as bushes in tropical conditions.

Attempts have been made to improve the patterns of cultivation, methods of pruning, application of fertilizers to maximise the leaf yield per unit area at minimum cost. Recent advances in various fields of moriculture both in developed and developing countries have shown that by systematic package of practices the yield of mulberry could be almost doubled and the quality of leaves improved. This increase in yield is attributed not only to the method of cultivation but also on checking the diseases of mulberry and controlling the pests. Further suggesting certain technique as a standard method for mulberry cultivation cannot be true as the ecological factors differ and the methods of silkworm rearing for which ultimate supply of leaf has to be effected varies. In tropical conditions frequent pruning is adopted to harvest over six crops a year, while recent developments in Japan have shown it is possible to raise three cocoon crops.

In this Manual the authors have described the technique of mulberry cultivation in vogue in various parts of the world. The description covers the botanical aspect of mulberry as also the mulberry cultivation. However, a detailed description of the various principles involved have not been dealt with.

A chapter on the diseases and pests of mulberry has also been covered in this Manual. Even though a detailed description of all pests and diseases of mulberry could not be covered due to lack of adequate information from various parts of the world, major pests causing concern for mulberry cultivation have been covered.

Two chapters on the food plants of Non–mulberry silkworms have also been included in this Manual. Various methods of cultivation of primary and alternative food plants of the three major non–mulberry silkworms viz., Tasar, Muga, Eri are also covered.

The authors thank Shri. Y.R. Madhava Rao, Shri. B.K. Kariappa, Central Sericultural Research and Training Institute, Mysore, and Shri. M.G. Das, Central Tasar Research Station Ranchi, for their assistance.

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MANUAL ON SERICULTURE

Volume-I — Mulberry Cultivation

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Part I

INTRODUCTORY

Chapter I

GENERAL ASPECTS OF MULBERRY

Mulberry forms the basic food material for silkworms and the bulk of the silk goods produced in the world are from mulberry silkworms. Sericulture involves agriculture, art and industry; mulberry cultivation involves various farming practices; silkworm rearing is an art in the hands of rural people; reeling of the silk from the cocoons formed by the worms is an industry of different financial investments. Scientific sericulture is the meeting place for agriculture and art, art and industry, ancient culture and civilization, the rich and the poor and it reflects the interdependence of these.

Production of mulberry leaves on scientific lines is essential for organising sericulture on sound economic lines. It is estimated that one metric ton of mulberry leaves is necessary for the rearing of silkworms emerging from out of one ounce of eggs, which will yield about 25 to 30 kg of cocoons of international standard. The cost of leaves works out to about 60 percent of the total cost of production of silk. The bulk of the leaves is required at the final stage of growth of the silkworm. One hectare of fertile land can produce about 15 to 40 tons of mulberry leaves over a twelve month period. This, however, depends on the favourable climatic conditions prevailing in the region; in the temperate and subtropical regions of Europe and Japan, about 15 to 20 tons of leaves per ha is produced in a year whereas in the tropical parts of India, under intensive cultivation practices, about 30 tons per ha could be harvested in a year. While mulberry leaf is available for rearing in Japan, the Republic of Korea and the U.S.S.R. for two to three rearing seasons a year, in the tropical countries like India, the leaves are harvested and utilized for silkworm rearing throughout the year.

Morus is the Latin word for mulberry (French: *muries,* Italian: *gelso,* Japanese: *lewwa*). Mulberry plant is exploited in different ways for commercial production of silk, as mulberry is the chief food for *Bombyx mori.* Mulberry leaf protein is the source for the silkworm to bio-synthesize the silk which is made up of two proteins, fibroin and sericin. Nearly 70 percent of the silk proteins produced by a silkworm is directly derived from the proteins of the mulberry leaves.

Mulberry is grown as a bush in tropical countries and as middlings and trees in temperate countries like Japan where silkworms can be reared only in three seasons a year. With an object of increasing the production of mulberry and reducing the cost of production, attention has been paid to intensive cultural operations including application of economic dosage of fertilizer and adoption of suitable irrigation schedules. Furthermore, research conducted on breeding of mulberry has resulted in evolving over 200 varieties of mulberry. Studies on the ecological factors and adaptability of these varieties have helped in selecting varieties suitable to different agro-climatic tracts. Studies on the horticultural aspects of the plants have helped in adapting various training, pruning and other plant regulatory cultural practices to make the plants grow as bush, middlings or trees, with economic production of leaf.

With efficient use of mulberry leaf, coupled with pruning programmes, it has been possible in sericulturally advanced countries like Japan to rear silkworms thrice a year, utilizing the second leaf harvest. In India, by following bottom pruning of the crop it has been possible to harvest more and better quality leaf. This has also made possible artificial hatching of bivoltine silkworm eggs and rearing of polyvoltine silkworms in a commercial manner in India.

The next scientific advancement in reducing the labour in harvesting leaf is introduction of mechanization of farming practices. Use of machines for cultural practices and for harvesting of leaves have helped to reduce the cost of production of mulberry leaf.

Irrigation is another influencing factor on the growth of mulberry leaves. It is observed that irrigation, coupled with fertilizer application, can increase the production of mulberry leaf seven to eight times, over dry farming conditions in the tropical regions. In addition, the quality of leaf improves and the leaf is made available throughout the year for hygienic growth of silkworms.

The soils grown to mulberry are mostly alluvial and volcanic types. Mulberry being highly responsive to fertilizer applications, the Japanese farmers have taken to the use of fertilizers on an adequate scale for achieving a high level of production. With the adoption of scientific production technology in mulberry culture, Japanese farmers have attained an average yield of over 15,000 kg of leaves per hectare, which in turn produce on an average 712 kg of cocoons and 117 kg of silk per hectare of mulberry plantation. Agronomical studies made in India have shown that 30,000 kg of quality leaf can be harvested per hectare per annum under tropical conditions.

As in the other crops, mulberry is also not free from pests and diseases. In order to check the pests and diseases, use of insecticides harmless to the silkworm has been suggested.

Bombyx Mori L., the mulberry silkworm being monophagous, the host specificity of these organisms is not mainly due to the nutritional superiority, i.e., in the amount of primary substances in mulberry leaves or green leaves of their choice, but due to the presence of attractants in the leaves. The attractants are odd compounds which attract the few insects which feed on them whereas they repell the others. These compounds are either glucosides, saponins, tannins, alkaloids, essential oils or organic acids, etc. They possess characteristic odour or taste and elicit sensory reactions to food in the insects, whereas proteins, carbohydrates have no taste or smell.

1.1 **Origin:** Mulberry is believed to be a native either of India or China and it is believed to have originated on the lower slopes of the Himalayas. Towards the year 2800 B.C. Chin–Nong, one of the successors of Empheras Fo–Hi taught cultivation of mulberry in China. Silk industry took its origin in the province of Chang–tong. According to Western historians mulberry culture spread to India from China through Kotan (Tibet) by about 140 B.C.

Area: While information on total raw silk production of many countries is available, the data on area under mulberry are not readily available. Since mulberry is planted along verges as trees and also as mixed crop without interference to other crops (with cotton in Russia) either true yield per acre or correct acreage cannot be computed. On the basis of global total raw silk production of 40,000 tons per annum it is estimated that about eight lakh hectares are required to produce this quantity of silk. The land area under mulberry in Japan reached a maximum of 7,08,277 ha in 1930 and declined to 1,62,000 ha in 1974. In India the land area under mulberry in 1971 was 1,04,885 ha together with about four million scattered mulberry trees grown in the northern parts of India (I.S. CSB. Vol. XII. No. 3, July 1973, page 15). In the Republic of Korea, the area planted with mulberry trees was scheduled to rise from 62,000 ha in 1966 to 1,35,000 ha by 1971 (Indian Silk, CSB, Vol. XII, No. 3, July 1973, page 14).

1.2 **Distribution:** A global survey of sericulture industry reveals that there are at least 29 countries where mulberry is cultivated and they are: (1) Japan, (2) China, (3) The Republic of Korea,(4) the U.S.S.R., (5) India, (6) Brazil, (7) Italy, (8) France, (9) Spain, (10) Greece, (11) Yugoslavia, (12) Turkey, (13) Sri Lanka, (14) Hungary, (15) Egypt, (16) Syria, (17) Poland, (18) Bulgaria, (19) Iran, (20) Lebanon, (21) Thailand, (22) Burma, (23) Bangladesh, (24) Afghanistan, (25) Cyprus, (26) the Republic of South Vietnam, (27) Indonesia, (28) Rumania, (29) Cambodia. There is no doubt that mulberry can grow and flourish in many other parts of the world and this aspect is being explored by the Food and Agriculture Organization of the United Nations (Figure 1).

1.3 **Latitude and Longitude:** The geographical position, i.e., the latitude and longitude of the mulberry growing tracts are given in Figure 1. It is found that most of the mulberry growing countries lie north of the equator, except Brazil which lies south of the equator (14⁰ to 23⁰S). Countries which lie in the belt of high range of latitude, i.e., 28⁰N to 55⁰N are as follows:

Japan 30⁰N – 41⁰N, China (Kiangu, Antueri and Chekiang), the U.S.S.R., the Republic of Korea, India (Kashmir), Yugoslavia, France, Spain, Italy, Greece, Cyprus, Turkey, Hungary, Syria, Poland, Bulgaria, Iran, Lebanon, Afghanistan and Rumania. All the above countries fall under the high income group, while countries with lower range of latitude, i.e..50⁰N– 28⁰N such as India, Brazil, Sri Lanka, Egypt, Thailand, the Republic of South Vietnam, Indonesia and Burma come under low income group.

A sericultural belt running parallel to the Tropic of Cancer circles the earth. Extending up to 50⁰N latitude, the temperate zone covers univoltine or one crop producing countries of Japan, China, the Republic of Korea, northern India, Burma, Iran, Turkey. the southern fringe of the U.S.S.R., Lebanon, Syria, Cyprus, Greece, Rumania, Bulgaria, Hungary, Yugoslavia, Spain, Italy, France and Poland. The tropical zone stretching to 10⁰S latitude contains polyvoltine,while southern China, Indochina, Thailand, central India, central Africa, Brazil and Peru, produce silk from non–mulberry silkworms.

Mulberry is raised in all prefectures of Japan, but mainly concentrated in Nagano, Gumma, Saitama, Yamanuashi, Ibaraki, Yamagata and Fukushima. Mulberry is distributed in China in nearly all parts extending from Manchuria in the north to the Isle of Hai–nan in the south. But the provinces in which sericultural industry is the most predominant are Cheh–Kiang, Kiang–Su, Sze–chueu and Shan–tung (Chan–tong). In the U.S.S.R., mulberry is cultivated in eleven republics, viz., (1) Uzbekistan, (2) Georgia, (3) Azerbaijan, (4) Turkenistan, (5) Tadjikistan, (6) Ukraine, (7) R.S.F.S.S.R., (8) Kirgistan, (9) Moldavia, (10) Armenia and (11) Kozakistan. In Italy, mulberry flourishes in the northern provinces of Lombardy, Venetia and Piedmont, which contribute about 77 percent of silk production and the remaining area is Liguria, Emilia and Tuscany. The principal mulberry growing states of India are Karnataka, West Bengal, Kashmir and Tamilnadu. Mulberry flourishes in France in Lyon Province and the principal mulberry growing areas are viz., Ardeche, Gard, Drome, Vaucluse, Var, Isere, Bouches–Rhone, Basses — Alpes, Lozere, Herault and Corsica. In Spain mulberry is grown in Murcia, Valencia and Aragon provinces. In Hungary, mulberry is a state monopoly and the principal mulberry growing area is Szekszard.

1.4 **Climate:** The climatic particulars of mulberry growing countries in the world are given in Table 1.

Table I

Climatic types of Mulberry growing regions

1.	Countries with mediterranean type of climate	France, Italy, Greece, Cyprus, Turkey and Yugoslavia.
2.	Countries with continental type of climate.	Spain, Hungary and Poland
3.	Countries with extreme variations in climate	U.S.S.R. and China
4.	Countries with monsoon type of climate	Japan, India, Sri Lanka, Burma, etc.

A perusal of the geographical position of these countries indicate that most of the mulberry growing countries are north of the equator except Brazil which lies south of the equator.

Mulberry can be grown under various types of climatic conditions, ranging from temperate and tropics. In the temperate climate, mulberry does not sprout during the winter season, while in the tropics the growth is continuous. The climatic conditions of major sericulture countries are given briefly below:

1.4.1 **Japan:** The climate is humid, warm, temperate and monsoonic. In the northern part of Japan winter is extremely cold and mulberry does not thrive and the southern parts are extremely warm and suitable for mulberry cultivation. Average temperature in Japan is 13.8°C. But as the sea stretches around the island, the climate is humid in summer providing suitable environment for the growth of mulberry.

1.4.2 **China:** A typical sericultural district of China has a mild and moist climate and extremely hot or cold weather is rare. The temperature is highest in the months of June, July and August, reaching about 37.7°C, and lowest in December and January dropping to about –1.1°C. The average for a normal year is approximately 18.8°C.

1.4.3 **U.S.S.R.:** Climate in the mulberry growing tract of the U.S.S.R. is characterized by the typical four seasonal set up, viz., spring, summer, autumn and winter. The contrast between summer and winter temperatures is striking. For example, in Uzbekistan the highest temperature recorded in summer is about 39–40°C while in winter, the minimum temperature is known to reach below 18°C. The extremes of temperature lead to complete defoliation of mulberry trees between November and March every year.

In temperate climate, mulberry sprouts in April and continues to grow up to October. From October to March the plant remains dormant due to severe winter. Thus temperature varies from 26.1 to 33.9°C the mean minimum temperature varies from 13.9 to 20.5°c.

1.4.4 **India:** The climatic conditions in India are favourable for luxuriant growth of mulberry and rearing of silkworms throughout the year. The temperature in Karnataka state, major silk producing state in India, ranges from 21.1°C to 30.0°C, while extremes of temperature are observed in West Bengal, the temperature falls below 15.5°C in winter and reaches as high as 36.6°C in summer. Climatic conditions in Kashmir are favourable to rear silkworms during May to October.

In most tropical countries favourable climate exists throughout the year for growth of mulberry. It is shown that annual production of mulberry could be almost double that of the temperate countries. Limitations of irrigation water in the tropical countries appear to cause the low returns of mulberry leaves. Where mulberry is grown in dry farming condition, the yield of leaf is poor and the production of quality of leaf is also limited to the rainfall received. The atmospheric humidity is also low, which indirectly affects the succulency and growth of mulberry leaf.

For the optimum growth of mulberry and good sprouting of the buds the mean atmospheric temperature should not fall below 13°C and if the temperature falls below this limit. mulberry remain in the dormant condition. The mean maximum temperature should not be above 37.7°C. Thus, for best mulberry growth, 23.9 to 26.6°C is found to be the optimum temperature.

Table 2

The range of temperature fluctuations prevalent in the mulberry tracts of Japan

1.	Annual average temperature	13.8°C
2.	Annual average daily highest temperature	13.7 – 21.5°C
3.	Annual daily lowest temperature	4.5 – 13.6°C
4.	Maximum highest temperature	31.9 – 40.8°C
5.	Minimum lowest temperature	6.4 – 25.5°C

1.5 **Rainfall:** Mulberry can be grown in a rainfall range of 635 mm to 2,500 mm. Under the low rainfall conditions, the growth of mulberry is limited due to shortage of moisture, resulting in low yields as prevailing in Karnataka state in India. Under low rainfall conditions, supplemental irrigation is necessary.

1.5.1 **Japan:** Japan receives well distributed rainfall of 1,000 mm to 2,500 mm, with a monthly average of 100 to 200 mm from March to October, coinciding with the sericultural season. Thus the distribution of rainfall is uniform especially during the growth phase of mulberry, the growth of mulberry is luxuriant resulting in high yields and no supplemental irrigation is required.

1.5.2 **China:** The rainfall is heaviest in the months of May, June and July and lowest in December and January. It is uniformly distributed throughout the year. The total rainfall is 1,440 mm spread over to 128 days of the year.

1.5.3 **U.S.S.R.:** In the U.S.S.R. the rainfall is highest ranging from 1,692 to 4,000 mm.

1.5.4 **India:** In India the rainfall is distributed unevenly. The total rainfall where sericulture is practiced on commercial lines ranges from 400 to 750 mm in Karnataka and over 1500 mm in West Bengal. However, mulberry is exposed to drought conditions during summer months, thus affecting the quality of leaves.

1.6 **Economics:** The suitability of the climatic condition for mulberry cultivation alone cannot sustain continued culture of silkworms on industrial scale in a country. The deciding factor is the economy of the industry, i.e., the cost of production which in turn reflects the efficiency of leaf production, utilization of the leaf by the silkworm race, the spinning quality of the silk, etc. Added to these, the availability and cost of labour are also important factors contributing to the cost of production.

Various scientific methods of mulberry cultivation have been adopted to maximize production in unit area of land and the cost analysis of input–output ratios have been worked out. The new innovations have been reported not only to increase the leaf production but also to reduce the cost of production of unit weight of leaf. Another interesting feature is the net profit earned from unit land through sericulture is more than any other agricultural or commercial crop, especially in developing and underdeveloped countries where the average income is low. The product of the land is mulberry leaf, which is converted into raw silk by rearing silkworms and the extraction of silk, both of which require large labour force. The quantity of silk produced varies from 20 to 120 kg per hectare. While even approximate monetary comparisons are difficult to make, the value of silk is obviously greater than the value of rice, sugarcane or any other crop produced per unit area of land.

From the point of view of national economy, one of the important advantages of sericulture is that it does not require much land. The area needed to produce one ton of raw silk depends on the intensity of mulberry cultivation and the quality of silkworm that is reared. With rainfed mulberry cultivation without the application of artificial fertilizers, and rearing in inferior quality of silkworm, 20 kg of raw silk is produced from one hectare of mulberry plantation. At the other extreme, cultivating the best varieties of mulberry on irrigated land with the application of fertilizers and rearing the most suitable silkworm races up to 120 kg of raw silk is produced from one hectare of mulberry plantation. For a country intending to start silk production, assuming that from the very beginning the most suitable variety of mulberry is cultivated and high quality silkworm races are reared, a yield of 40 to 60 kg of raw silk could easily be produced. On this basis a foreign exchange in the range of Rs. 5,000 to Rs. 9,000 per hectare of mulberry can be expected.

Part II

BOTANICAL ASPECTS OF MULBERRY

Chapter 2

BOTANICAL DESCRIPTION

Mulberry belongs to the genus *MORUS*. The number of species varies according to the author, as the species classified by some taxonomists are considered as varieties of the same species by the others. In any case, the number of species belonging to the genus *Morus* is more than twenty. There is considerable variation in each and every character of the species and the varieties described so far. Hooker (1885) has given the botanical description of the genus *Morus* as follows (Figure 2):

Trees or shrubs. Leaves alternate, entire toothed or three lobed, base three to five nerved, stipules small, lateral, caducous. Flowers mono or dioecious, spikate. Male flower sepals four imbricate. Stamens four, inflexed in bud. Pistillode turbinate. Female flower sepals four, ducussate, imbricate, accrescent and succulent in fruit. Ovary included straight one celled, style central, two partite or two fid; ovule pendulous; fruiting spikes or heads many, achenes enclosed in the succulent perianths. Seed subglobose, albumen copious fleshy; embryo incurved, cotyledons oblong equal, radicle ascending incumbent — species few, tropical and temperate.

2.1 **Plant habitat:** The plant is a perennial one, living for a number of years either cultivated or in wild state. Depending upon the type of cultivation, the plant is grown as a bush, tree or a middling. The plant is of branching type and the branching character varies considerably due to the influence of different factors, such as the type of cultivation, mode of training, fertility of the soil, rainfall, etc. In a field crop, profuse branching is preferred, as the production of leaves will be more.

2.2 **Plant height:** The plants when allowed to grow as trees attain a height of 22–25 m. with a girth of the trunk about eight m. in the case of *Morus serrata*. In India, in the multivoltine areas like Karnataka and West Bengal, the plants are grown as bushes by pruning the plants once a year or after every crop (Figure 2c). In the univoltine area of Jammu and Kashmir, the plants are grown as trees mostly wildly in nature (Figure 2b). Where the trees are grown as a fence, they are allowed to grow to the required height and then pruned at the desired height every year. In some areas the plants are allowed to grow as middlings, i.e. they are pruned at a height of 45 to 90 cm from the ground level, every year. The bush and middling usually attain a maximum height of 1.5 to 1.8 m. and hence makes it easy for the harvesting of leaf.

2.3 **Stem:** Mulberry plants show a number of stem colours depending upon their species, climate and origin. The Mysore Local, Kanva-2 and Berhampore varieties of the species *Morus indica* are white to greyish white in colour. The Japanese varieties like Shimonuchi, Ichinei and Mizusawa are reddish brown in colour; Kairio-Nezumigaeshi, Ichinose and Kokuso-27 are grey or greyish brown; Roso, Kario-roso, Kosen and Gosho-erami are yellowish brown; the Russian variety Sannish is greyish pink.

2.4 **Bud:** In mulberry, generally one bud is found in the axil of a leaf. Sometimes two more independent buds on either side of the main bud are also found (Figure 3). These are called accessory buds. More often some of the axillary buds of the scale leaves of the main bud peep out of the bud as though they are the accessory buds. They are generally called "scale buds". Buds are protected by the covering of young leaves which are, in turn, covered by older and oldest leaves (Figure 4). The growing point emerges as a shoot under favourable climatic conditions. Generally, mulberry varieties growing in tropical climatic conditions sprout throughout the year.

The rate of sprouting of vegetative buds is of primary consideration in introducing a variety or species in an area. Mulberry varieties grown in Mysore and West Bengal sprout throughout the year, facilitating the sericulturists to rear the silkworms throughout the year (Figure 5). The size, shape and position of the axillary bud varies from variety to variety.

The buds of plants under extremes of climatic conditions do not grow and such buds are called resting buds. Winter resting buds are also found in mulberry species growing in temperate regions. In some plant species the outer leaves of the buds become modified into thick brown structures. The cell contents get absorbed and become bad conductors of heat. These scale leaves drop off at the advent of favourable conditions and the young leaves begin to unfold. They leave a number of close set scars which indicate the plant age (Figure 6).

2.5.1 **Causes for dormancy in bud:** Earlier physiologists were of the opinion that low temperature, nitrogen deficiency, inactivation of enzymes due to excessive accumulation of carbohydrate, photoperiodism etc., might be responsible for dormancy. Recently, however, evidences have accumulated to show that dormancy is mainly due to auxins present in the bud. The terminal bud contains more auxin than the lateral bud during dormancy. It is not established as yet whether the lateral bud dormancy is due to excess of hormone they receive or less of hormone. Yahira and Hayashi (1971) analysed the auxin content of the dormant buds and suggested that there are at least three growth factors responsible for dormancy.

2.5.2 **Methods of breaking dormancy in buds:** (a) **Mechanical:** Sometimes even under tropical climate, during winter period, the buds do not sprout quickly. In order to hasten the sprouting in such buds, the plant shoots after leaf harvest are bent in such a way to form an arch. Due to this certain amount of stress and strain is exerted on the scale leaves of the buds and they drop off. Then buds start emerging (Figure 7).

(b) **Chilling treatment:** Gururajan (1962) reported the success of breaking dormancy in buds of *Morus nigra* by subjecting them to a low temperature of 0 to 6°C.

(c) **Chemical treatment:** Iwata (1970) reported the effect of chemicals such as methyl caprate on the sprouting of mulberry buds and retardation of growth of mulberry plants. Mulberry plants grown were sprayed by aqueous emulsion of methyl caprate in summer with varying concentrations ranging from 0.01M to 0.2M. The tender portions of the plant were retarded with the sprays at the concentration of 0.01M and the terminal buds were injured severely at concentrations higher than 0.25 M. Axillary buds of mulberry treated with higher concentrations than 0.2 M were forced to sprout earlier with vigorous recurrent shoots within 50 to 60 days after treatment.

Iwata, *et al* (1972) reported that spraying of etherel (ethylene releasing agent) of 800 ppm concentration on the shoots of growing mulberry plants inhibited the terminal buds but the lateral buds sprouted. Though the sprouting of vegetative buds through chemicals was very unsatisfactory and the recurrent branches were irregular, the nutritive quality of the leaf as judged by the silkworm rearing was as good as those leaves which were obtained through natural sprouting.

2.6 **Leaves:** The size of mulberry leaf varies in different species and varieties. Varieties like Kanva-2 are characterized by large leaves and varieties like "Mysore Local" bear only small leaves. The leaf size is an important character taken into consideration in selecting high yielding varieties.

The leaves are simple, alternate and stipulate (Figure 8). The size of the stipule varies with variety, such as 1.5 to 2.0 cms in *Morus nigra* and Chinar variety of Kashmir (India). The stipule protects the young leaf and as the leaf matures the stipule drops off. Leaves are petiolate, the length of petiole varies from 2.5 to 7.5 cm with a groove on the dorsal side. Mulberry is unique in possessing both lobed and unlobed leaves on the same twig. Varieties like Kanva-2, Kosen, etc, have only unlobed leaves and varieties like Mysore local and Berhampore local have mostly lobed leaves (Figure 9). The number of lobes per leaf varies from one to seven and in the variety Sujanpur-5, the leaf is highly dissected with numerous lobes.

The lamina of the leaf is usually glabrous but may vary with the variety. The leaves of the variety Kairio–Nizumagaeshi are coriaceous and of Ichehai are hirsute. The size of the lamina varies from variety to variety and it measures nearly 30 cm in length along the midrib and about 25 cm breadth at the widest region in the variety Goshoerami and Mizusawa wherein the leaves are unlobed. The thickness of the leaf is about 100–200μ. The shape of the leaf is generally ovate or ovate–cordate as in the case of *Morus indica, M. serata, M. laevigata,* etc. The shape of the leaf is decided by the main, side and bottom veins. The base of the leaf may be curved, i.e., cordate or straight and truncate or ordinary. The leaf baseis truncateinthe case of *Morus indica* var. Assamajati, and cordate in *M. indica* var, Kanva–2 and in the Japanese variety, Kosen. The leaf tip is generally of four types, viz. acute, double acute, acuminate and long acuminate. The teeth are generally crenate but various types such as serrate,dentate, dentate–serrate, serrate–dentate, etc., occur. The venation of the mulberry leaf is multicostate reticulate. The leaf base is generally three nerved as in the case of *Morus alba.*

2.6.1 **Phyllotaxy:** Generally it is of 1/2 or 1/5 in the Yamaguwa type of mulberries of Japan such as Shimonouchi, Ichehai, Mizusawa, etc.,and 2/5 in many of the Karayamaguwa and Roso types such as Kairio–Nezumagaeshi, Ichinose, Roso, Kosen, Goshoerami, etc. Most of the Indian varieties are five ranked (Figure 10).

2.7 **Inflorescence:** The inflorescence of mulberry is a CATKIN with its characteristic pendent or drooping peduncle, bearing unisexual flowers. The plants are generally DIOECIOUS (occurence of male and female catkins on separate plants) but the occurence of MONOECIOUS (both occur on same) plants is also not uncommon. Very rarely bisexual flowers are seen due to development of pistillodes and staminodes. Sometimes in variety Goshoerami the lower portion of the catkin bears female flowers and male flowers in the upper portion.

2.7.1 **Male catkin:** The male catkin is usually longer than the female catkin measuring 2.5 to 5 cm long (Figure 11). The flowers are very loosely attached to the peduncle. The inflorescence is axillary and branched in certain cases. Usually they are in clusters. After pollination the male catkin becomes pink, dries and drops off as a whole.

2.7.2 **Female Catkin:** The female catkin is axillary, sometimes occurs in clusters (Figure 12). It is usually shorter than the male catkin measuring 1.5 to 3.5 cm but in certain species like *M. serata* and *M. laevigata* the femalecatkinsmeasures 10 to 12 cm. The flowers are stiffly attached to the peduncle. After pollination and fertilization the entire inflorescence becomes a multiple fruit.

2.7.3 **Flower:** The flowers of mulberry are small, usually sessile or infrequently shortly pedicillate, regular and unisexual.

2.7.4 **Male flower:** The male flower consists of four perianth leaves (Figure 13) arranged in two whorls with imbricate aestivation. The anterio–posterior perianth leaves are outside and the perianth leaves in the transverse plane are inside (Figure 15). They are green, homochlamydous, sometimes the margins of the perianth leaves and the outer surface are provided with hairs.

The androecium consists of four stamens arranged opposite to perianth leaves. The filaments of the stamens are bent inward in bud condition (Figure 14). Each stamen has a broad filament and a narrow top on which two anther lobes are fixed in versatile condition. Anthers are dithecems with longitudinal dehiscence; the pollen grains are round, dry, light and dust–like with smooth exine.

2.7.5 **Female flower** : The female flower consists of four perianth leaves arranged in the same manner as in the male flower (Figure 16). The perianth leaves are persistent. Due to fertilization the perianth leaves of the female flower also get stimulated, become thick, contain a juicy material which contributes in the formation of the fruit.

The ovary is made up of a bicarpellary syncarpous, superior and unilocular containing a single pendulous ovule attached to the margin of the ovary (Figure 17a and 17b). There is a single style. The length of the style is botanically an important character in distinguishing various species of mulberry (Figure 19). Those which are having longer styles are grouped under Dolichostylae and those with shorter styles are grouped under Macromorus. Certain species of mulberry like *Morus bombycis, M. kagayamae,* possess a long style, whereas species like *M. formosensis, M. tillaefolia* possess a short style. The stigma generally bifid, however, rare occurrence of trigid stigma has also been reported. Sometimes, the stigma may be papillose as in *M. rotundifolia* or may be pubesent as in *M. mizuho* and *M. tiliaefolia.*

2.7.6 **Pollination:** Since the flowers of mulberry are unisexual, only cross pollination takes place. The chief pollinating agent in mulberry is wind. The flowers of mulberry are well adapted to suit their pollinating agent. The following are some of the anemophilous characters seen in mulberry flowers:

(i) "The wind bloweth where it listeth" is a common saying. Hence transference of pollen grains to their destination by the agency of wind depends much upon change. To avoid this difficulty anthers produce a large quantity of pollen and there is much waste.

(ii) In the male catkin of mulberry, the flowers are loosely attached to the peduncle; as they are flexible, they can be easily shaken off by wind and for every gust of wind a large quantity of pollen is wafted.

(iii) The flowers are small and inconspicuous, they possess neither honey, colour, nor emit any smell.

(iv) Perianth leaves are very much reduced. Consequently the essential organs (androecium and gynoecium) are well exposed to wind currents.

(v) Anthers are versatile and situated on long slender filaments which peep out of the flowers.

(vi) The filaments are long and bent inward in bud condition.

(vii) The pollen grains are dry, dust–like, small and light. They are provided with smooth coats and never stick to one another.

(viii) The stigma is very much pronounced exposing a large surface to the wind current and this increases the chances of receiving pollen. They are branched, brush or feather–like (Figure 18).

2.8 **Seed:** Typical tree whose seeds are to be used for propagation by sexual means is selected from which dark purple coloured ripe fruits are collected. These fruits are kept for one day for softening the pulp taking necessary precautions to prevent the pulp from rotting. The next day, these fruits are transferred to a trough containing water. Then by constant kneading of the fruits the seeds become squeezed out of the pulp. The water is decanted and the seeds are taken out, dried and stored under dry conditions.

2.8.1 **Structure of seed:** Mulberry seed is oval in shape with a nearly flat surface at the micropylar region (Figure 20). On one edge is found an elongated streak the HILUM. At one end of the hilum is found a small pore the MICROPYLE, through which the seed absorbs water when soaked. The seed coat consists of two layers, the outer hard and brittle layer TESTA and the inner thin papery and slightly brownish layer TEGMEN. When the seed coat is removed the kernel is disclosed. This consists of an ENDOSPERM in which the material is stored and an EMBRYO, which lies curved in the endosperm (Figure 21).

The seeds also contain 25–35 percent of a yellow drying oil with the following characteristics: sp. gr. 0.924–0.926, saponification value 190–192, iodine value 140–144 and R.M. value 0.10 to 0.35. Liquid fatty acids constitute the major part (80–90 percent) of the total fatty acids of the oil. It is reported that in Beypazi area of Ankara province of Turkey, mulberry seed oil is preferred to butter or olive oil.

The embryo consists of a primary axis (plumule and radicle) and two COTYLEDONS (figures 22a and 22b). On germination, the plumule gives rise to the shoot system and the radicle to the root system. The size and weight of the seed varies with the variety. The seeds of polyploid species weigh more than those of diploids.

2.8.2 **Polyembryonic seed:** Rare occurrence of seeds giving rise to two identical seedlings has been reported. Such seedlings were thought to be polyploids. Generally embryo is developed only from the egg cell in the ovule. Sometimes embryos may be formed from nucellar tissues also. The occurrence of more than one embryo is called POLYEMBRYONY. It may result in the following ways:

(i) The pro–embryo may become separated into two or more portions.

(ii) More than one cell of the embryo may develop into an embryo.

(iii) There may be two or more embryo–sacs in an ovule.

(iv) Budding or proliferation of the cells of the nucellus or integuments.

(v) Identical seedlings may also arise if the egg and one synergid are fertilized by the two male gametes discharged from the same pollen tube.

2.8.3 **Storage of seed:** Mulberry seeds may be viable for a few weeks or may be at the most for three months beyond that they may not be viable. However, if the seeds are stored under controlled temperature and humidity conditions, their viability may be prolonged for some more time.

(i) Seeds remain viable for longer period of time at low temperature, usually 5^{0}C than when stored at room temperature.

(ii) Low relative humidity is usually more favourable for prolonging the life of seeds than high humidity.

2.8.4 **Viability test for seed:** (1) **The behaviour of excised embryos:** The test is based on the behaviour of embryos when removed from the surrounding tissues of the seed. If an embryo is carefully removed out of the seed and placed on moist filter paper at room temperature, the embryos of viable seeds show different types of growth behaviour whereas non–viable seeds deteriorate rapidly. The embryos may also be placed in a granulated peat mass or on sterilized nutrient agar for germination. This method has a high reliability.

(ii) **The use of dyes:** The seeds are soaked overnight in water and are transferred to a solution of Triphenyl tetrazolium chloride (TTC) for a few hours. The micropyle of the living seeds takes a pinkish colour and the non–viable do not take any stain.

(iii) If the seeds are soaked in distilled water and electrical conductance of the bathing solution is tested, the increase in conductance is roughly proportional to the percentage of dead seeds.

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Chapter 3

CLASSIFICATION AND VARIETIES

Mulberry is a fast growing deciduous tree occurring in sub-tropical, tropical and temperate climates. It occurs indigenously in the North and West Asia, Thailand, Malaya, Burma, Bangladesh, India, Pakistan, Turkey, North Iran, Armenia, Syria and Arabia. In Europe, it is found in Italy, France, Austria, Hungary, Spain, Rumania, Greece and Southern U.S.S.R. In America it occurs in the southeastern part of Canada, eastern parts and coastal districts of the United States, Mexico and in Central and South America.

There is considerable amount of confusion in the taxonomy of the genus as adopted in different countries, perhaps because of its adaptability to cross pollination in nature wide variations in plant characters have crept in.

The rational method of classification of mulberry species should generally be based on "genome constituents". There are more than a thousand varieties including wild and cultivated forms, some of which are sterile. Therefore, the classification of mulberry should be based on external characters like the leaves, flowers, fruits etc.

Taxonomists in different countries have adopted different systems. Ledebour (1846–1851) used papillae and pubescences on the stigmata for classifying *Morus alba* and *M. nigra*. Bureau (1873) classified mulberry into two species on external characters and divided *M. alba* into two sections by the length and shape of the female inflorescence and syncarp, and subdivided each section by the length of the style of the female flower. Brandis (1906) classified the mulberry species into two sections by the length of the style and subdivided one section by the length and shape of the syncarps and another section by the features of the leaf. Koidzumi (1917–1923) grouped mulberry into two sections on the length of the style of the female flower as *Dolichostylae* and *Macromorus* and each subdivided on the features of stigma, as shown below:

A. Dolichostylae:		
(a) Pubescentes	*Morus arabica* Koidz.	(Arabiyaguwa Mizuhoguwa)
	M. mizuho Hotta	
(b) Papillosae	*M. mongolica* Schn.	(Chosenguwa Oniguwa)
	M. mongolica var. *diabolica* Koidz.	
	M. nigriformis Koidz	(Karaoniquwa)
	M. notabilis Schn.	(Marubaguwa)
	M. bombycis Koidz	(Yamaguwa)
	M. rotundifolia Koidz	(Shamuguwa)
	M. acidosa Griff	(Shimaguwa)
	M. kagayamae Koidz	(Hachijoguwa)
B. Macromorus:		
(a) Pubescentes	*M. serrata* Royb	(Tenjikuguwa)
	M. nigra L.	(Kuromiguwa)
	M. tiliaefolia Makino	(Keguwa)
	M. cathayama Memsl.	(Karakeguwa
(b) Papillosae	*M. mosozygia* stapf.	(Afurikaguwa)
	M. laevigata Wall.	(Nagamiguwa)
	M. insignis Buv.	(Amerikaguwa)
	M. macroura Miq.	(Mareiguwa)

M. rubra L.	(Akamiguwa)
M. mollis Rusby.	(Yaharaguwa)
M. celtidifolia Kunth	(Enokiguwa)
M. microphylla Buckl.	(Himeguwa)
M. boninensis Koidz.	(Ogasawaraguwa)
M. lhou Koidz	(Roguwa)
M. alba L.	(Karayamaguwa)
M. atropurpurea Roxb	(Kantonguwa)

Hotta (1930) divided mulberry species into two groups according to the shape and situation of cystolith cell in leaves. *Dolychocystolithiae* and *Brachycystolithiae.*

Group 1: Dolychocystolithiae;

Morus bombycis, M. kagayamae and *M. australis.*

Group 2: Brachycystolithiae:

Morus latifolia, M. alba and *M. tilaefolia.*

He, however, in his report in 1954 grouped mulberry species into two sections as Koidzumi, and subdivided basing on the characteristics of stem and leaf (Figure 23b).

Katzumata (1971) proposed another classification based on the type of the idioblasts. According to him there are four types of idioblasts in mulberry leaves (Figure 23a). Type A consists of idioblasts without projection having three to ten microns above the epidermis, e.g. *Morus kagayama.* Type B consists of idioblasts with a small projection above the epidermis, varying from three to twelve microns, as in *Morus multicaulis, M. alba, M. bombycis, M. mizuho* and *M. nigra.* Type C consists of idioblasts with a medium projection of 18 to 32 microns above the epidermis as seen in most of the races of *Morus bombycis,* and in some races of *Morus alba, M. multicaulis, M. tilifolia* and *M. yoshimurai.* Type D consists of idioblasts with a big projection of 40 to 80 microns above the epidermis as in *Morus laevigata.* Based on the above characters, Katzumata divided the species into a number of types as given hereunder.

Morus bombycis K.

Type B: Akazaya, Amagiyaso, Ohyashima, Kachachi, Kawaguwa, Kamijo, Kenmochi, Shiroshita, Shimizuwase, Chiyozuru, Chinba, Tsuruta, Kairyotsuruta, Nagabashinju, Fugenso, Hijirimen.

Type C: Akagi, Gummaakagi, Akameyanagida, Anahagiguwa, Akashidare, Asahiwase, Iwatemaru, Ichiba, Itowase, Izumiguwa, Igakuwa, Inouewase, Kamimurawase, Enshutakasuke, Owaritakasuke, Ohbatakasuke, Aokitakasuke, Negoyatakasuke, Ohwase, Kanime, Kanikobore, Kinjo, Kubotawase, Tsukumo, Kuroohfushimagari, Kuroshodo, Gorojiwase Kozaemon, Sapichi, Shimanouchi, Shihozaki, Shinza, Jukima, Josen, Seisuke, Sosukewase, Takahashi, Takinokawa, Takehayawase, Tajimashidar Chosenzairaishu, Tsurukuwa, Tsubakikuwa, Tosuke, Nagiguwa, Nemurasaki, Shunshoku, Bando, Hayasegawayaso, Hinowase, Himetsuru, Hiranoguwa, Fushimagari, Mizusawa, Midareguwa, Murasakiwase, Mukashiyamato, Meguroyaso, Morikiyo, Mokuwase, Yajima, Rokurowase.

Morus alba L.

Type B: Akatako, Inaguwa, Ichinose, Kairyoichinose, Eijiwase, Kinmeso, Kurokobushi, Kokuso No. 27, Shiroshodo, Shinpaku, Shirokawakeiso, Sujikuwa, Daruma, Kairyodaruma, Tanikaze, Tanakaiyaso, Jumonji, Kairyowasejumonji, Kairyojumongi, Gummajumonji, Takedajumonji, Ohzekijumonji, Kurojumongi, Akagijumonji, Shirakijumonji, Kawanejumonji, Tsurukuwa, Tenmokuyotsume, Tomeiso, Nakamagi, Nishikiguwa, Nezumigaeshi, Shironezumigaeshi, Kairyonezumigaeshi, Fukushimachha, Gummaohha, Ohha, Hiroeso, Benten, Midorinishiki, Yatsubusa, Kairyoohha, Heijiro, Hosoe.

Type C: Ichibei, Akameichibei, Akagiichibei, Kurokiichibei, Tanbaichibei, Aoichi, Ryomenso, Onnajumonji, Nagase, Shukakuichi, Takowase, Shirotaka, Aotako, Ohgontako, Tanbaki, Yoroso.

Morus multicaulis P.

Type B: Akita, Kairyoakita, Ohshimaguwa, Kawaura, Kasuga, Kagemoriso, Kaso, Kairyoru, Kumonryu, Garyu, Ginbasho, Kurimoto, Kumagariso, Keiso, Kokuso No. 13, Kokuso No. 20, Kokuso No. 70, Kosen, Goshoerabi, Sakaeso, Shiso, Shinshironishiki, Jinso, Seijuro, Daishukaku, Nagannuma, Hinodeso, Bishamon, Philippin, Fusomaru, Fujibasho, Fukkokuguwa, Roso, Aokawaroso, Maruharoso, Aokiroso, Kairyoroso, Shiromeroso, Kairyoakameroso, Rohachi, Rokokuyaso, Wasemidori.

Type C: Kanraso, Kokuso No. 21, Dainoguwa.

Morus mizuho H.

Type B: Kyohei, Showa, Kinryu.

According to another classification, from the point of view of sericulture, all the varieties grown in Japan are divided into three types, Yamaguwa, Karayamaguwa and Roguwa. Varieties belonging to the first group are of Japanese origin and the other two were imported from China during different periods.

Yamaguwa type

Varieties: Ichihei Akagi, Shima-no-uchi, Tsuruda, Hidaguwa, Yanagida, Yamanaka, Takasuke, Yogohachi, Enshutakasuke, Negoyatakasuke, Komaki, Takahashi, Aometakahashi, Senmatsu, Yohei, Sobo, Kenmochiguwa, Takino-guwa, Sapprorosuwa, Jushima, Mizusawa-guwa, Sosukewase, Goroji-wase, Takagawawase, Fushimagari.

Karayamaguwa type

Kairyo-nezumigaeshi, Ichinose-guwa, Hosoe, Kumonryu, Tomleiso, Reiso, Kobata, Nezumigaeshi, Kairyo-wase-jumonji, Kasuga, Inaguwa, Shyukakuichi, Jumonji, Fukushima-oha, Tako-wase, Shiroshita, Yotsume, Yatsubusa.

Roguwa type

Roso, Kairyo-roso, Shirome-roso, Akame-roso-Rokokuyaso, Kanraso, Goshosen, Misonoguwa, Seijuro, Kosen, Basho, Azumiguwa, Rohachi, Murasaki-wase, Kurimoto.

(Figure 23c)

3.1 **European varieties:** Mulberry which is a native of China entered Europe probably through India. It is said to have been imported into France by the end of the twelfth century. The following varieites of mulberry are found in Italy (gelso is the Italian word for *morus*):

G. della valtellina	G. di Spagna	G. morettiano
G. della acchio	G. romano	G. delle Filippine
G. mantovano	G. trentin	G. Ihon.
G. di Toscana	G. cattaneo	

The following varieties of *morus alba* have been reported from France (murier is the French name for *Morus*):

Murier sanvageon	M. rebelaire	M. colombasette.
M. rose	M. colombassa	

3.2 **Indian varieties:** There are many kinds of mulberry, of which *Morus alba* (var. *indica* and *laevigata*) and *Morus serrata* grow wild in the Himalayas. Several other varieties have also been introduced in this country with success. There are *Morus nigra, M. multicaulis, M. sinensis* and *M. philippinensis.*

The classification of Indian varieties of mulberry as in other countries is also much confused. Brandis (1906) described four species, *Morus alba* Linn., *M. laevigata* (*M. glabrata* Wall.), *M. indica* and *M. serrata* Roxb. (*M. Pabularia* Decne). Hooker (1885) recorded *M. indica* Linn., *M. serrata* Roxb., and *M. laevigata* Wall. and *M. atropurpurea* Roxb., a Chinese species, closely allied to *Morus alba.* Mukerjee (1899) treated *Morus indica* and *M. laevigata* as varieties of *Morus laevigata* and maintained *Morus serrata* as a distinct species. He, however, regarded *Morus indica, M. laevigata, M. multicaulis, M. sinensis, M. philippinensis* as varieties of *M. alba.*

Kadambi (1949) reported that many varieties of mulberry were introduced into India from Europe, China and probably from Japan or the Philippines. *Morus multicaulis* commonly known as a Philippine variety was introduced in India from China or the Philippines in about 1840. *Morus alba* var. *moretti, Morus nigra* var. *lacinata* and *Morus japonica* were introduced from Europe. According to him the most important types of mulberry grown in India for rearing silkworms are *Morus abla* var. *multicaulis* as a bush crop and *Morus alba* var. *atropurpurea* as a tree. Yegna Narayana Iyer (1954) recorded mulberry varieties sometimes referred to species, *Morus alba, M. indica, M. nigra, M. sinensis* and *M. multicaulis.* Gururajan (1960) suggested grouping of all the cultivated forms of mulberry into three species namely *Morus alba* (includes bush mulberry cultivated in Mysore and Tamil nadu), *M. bombycis* (includes Berhampore variety) and *Morus latifolia* (includes tree mulberry grown in Kashmir and Uttar Pradesh) based on the principle of classification adopted by Hotta (1954).

3.2.1 ***Morus alba:*** Cultivated in Punjab, northwest Himalayas ascending to 3500 m. The trees grow to a height of 10 to 15 m. and are wild and cultivated for their fruit and timber.

3.2.2 ***Morus indica:*** Most of the Indian varieties of mulberry belong to this species. They are moderate sized deciduous trees, distributed in the lower Himalayan and sub–Himalayan tracts from Kashmir to Sikkim, ascending upto an altitude of about 2500 m. In the other regions in India, particularly in Bengal and Assam in the northeast and in southern plateau in Karnataka and Tamilnadu ascending up to 1500 m. There are several varieties falling under this species, raised mostly as bushes.

3.2.3 ***Morus serrata:*** This species grows as trees upto a height of 20 to 25 m. with a trunk girth of about nine m. in temperate Himalayas from Kumaon Hills westward, up to an altitude of 3000m.

3.2.4 ***Morus laevigata:*** This species is distributed in tropical and sub–tropical regions from Indus valley to Assam, wild and cultivated ascending to 1500 m.

In addition to these species, there are a number of cultivated forms belonging mostly to *Morus indica* and they are listed hereunder (Figure 23d):

1. Assamabola
2. Jatinuni
3. Sujanpur–1
4. Sujanpur–2
5. Sujanpur–3
6. Sujanpur–4
7. Sujanpur–5
8. Kaliakutahi
9. Dhar Local
10. Mysore Local
11. Berhampore Local
12. Brentul
13. Botatul
14. Tsaritul
15. Kanva–2

3.3 **Varieties of West Java:** There are eight species distributed towards the western part of Java. All these species are found to exhibit certain peculiarities which have been recorded as variants of the species. The following are the species found in west Java with certain distinct characteristics:

1. *Morus Nigra* L. – One strain belonging to this show lustrous leaves.
2. *M. alba* L. – Thick brown coloured shoots.
3. *M. multicaulis* P. – Brown coloured bark.
4. *M. alba* L. var. *tartarica* – Bark purple colour in young shoots and long style.
5. *M. alba* var. *macrophylla* – Big projected idioblasts.
6. *M. australis* P. (*M. acidosa* G.). – Short styles and irregular leaves.
7. *M. cathayana* H. – Same as *Morus alba.*
8. *M. macroura* M. and *M. bombycis* K.

3.4 **Varieties of the Republic of South Vietnam:** Varieties of the following species have been reported to be utilised for silkworm rearing in The Republic of South Vietnam:

1. *Morus alba* (Dau bau Trang)
2. *M. nigra* (Dau bau Der)
3. *M. nigra* (Dau duoi)
4. *M. laevigata* (Dau cay).

The important feature of all the species is that they are evergreen and are also different from those of Japan and west Java to a very great extent (Katzumata, 1973).

3.5 **Varieties of the U.S.S.R.:** Most of the species of the U.S.S.R. are *Morus Multicaulis, M. alba* variety *tartarica* and *Morus nigra.* Majority of the species are resistant to cold climate. Besides the indigenous varieties, there are many imported from other countries and also evolved through hybridization and selection. The popular varieties of the U.S.S.R. are:

1. Local (Paiwandi)
2. Zarif Toot
3. Kol Toot
4. Tadjik seedless variety (triploid)
5. Pioneersky
6. Uzbeksky (tetraploid)
7. Tashkentsky
8. Octobersky
9. Sikhgez toot
10. Azari toot
11. Khanlar toot (triploid)
12. Amin toot
13. Firudin toot
14. Khazar toot (triploid)
15. Makhsalu toot
16. Wagif toot
17. Bedana local
18. Russian local
19. Grusia
20. Hybrid mulberry (Armenia)

A number of mulberry varieties and forms belonging to different species and sub-species are present in different countries. Some of them are wild and many of them are cultivated, some are exotic and the others indigenous. It has become possible for the mulberry breeders to exploit the desirable characters like natural heterogenity and adaptation to vegetative propagation in evolving superior and economic strains of mulberry suitable to different agro climatic regions of the world by means of plant introduction, hybridization and selection, polyploidy breeding and mutation breeding.

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Chapter 4

ANATOMY AND EMBRYOLOGY

4.1 **Anatomy of the Root:** Mulberry is a deep rooted perennial plant. Its root system is very well developed though the growth and spread of the root depend upon the texture of the soil. The root tip shows the same structure as in other dicotyledonous plants. There is a clear differentiation of root cap which protects the growing meristamatic tissue from dessication and injury by the various soil organisms. The root hairs which are ephemeral serve the function absorption of water and salts from the soil.

4.1.1 **Internal structure of a root:** The morphology of a transverse section of the root before the formation of the secondary tissues is described below.

There is a single layered epidermis which consists of tubular shaped cells, closely arranged without inter–cellular space. Its outer walls are not cutinised and a few of the epidermal cells enlarge into root hairs. Below the epidermis there is a large cortex which consists wholly of parenchyma cells. There is a clear single layered endodermis enclosing the pericycle and vascular bundles. The vascular bundles are diarch, sometimes triarch, radial and without cambium. The pericycle is many layered which later forms the cork cambium (Figure 24).

4.1.2 **Structure of a secondary root:** The knowledge of anatomy of a root is of primary importance in the vegetative propagation such as selecting a proper plant for preparation of cutting and stock for grafting. Some of the cells of parenchyma outside the protoxylem convert themselves into a small strip of cambium. These cambial strips divide and redivide to produce a sinuous cambium layer which later becomes circular. The cambium cuts off cells towards outside and inside. Simultaneously some of the cells of the pericycle also convert themselves into meristematic cells to form cork cambium. The cork cambium cuts off cells towards outside and inside, more cells towards inside than outside, thus more of secondary phloem is produced. The primary xylem strand remains undisturbed as main medullary ray. Thus in the secondary root, there is a thick bark including the primary cortex. The cork consists of rectangular cells whose contents are absorbed. Below the cork is the secondary phloem and secondary xylem are formed from the activity of the cambium. The roots with two or three layers of cambium are preferred for purposes of grafting or cutting (Figures 25a, 25b and 25c).

4.2 **Anatomy of stem:** The anatomy of the stem is similar to that of any dicotyledenous stem. The primary stem consists of a single layered epidermis with tubular shaped cells closely arranged without inter–cellular space. The outer cells of the epidermal cells are cutinised.

Some of the epidermal cells are drawn into unicellular hairs wich protect the plant from injurious insects and also minimize the rate of transpiration. These epidermal hairs are coarse and profuse in polyploidy species. Below the epidermis is a multilayered cortex which consists of colio parenchyma cells. Some of the cells contain chloroplasts. There are many laticiferous cells in the cortex which are the storehouses of organic excretory products. There is a single–layered endodermis with conspicuous barrel–shaped cells. The pericycle is many layered. The vascular bundles are few, collateral, conjoined, open and endarch. There is a conspicuous medulla (Figure 26).

4.2.1 **Secondary stem:** The secondary stem of mulberry shows the following tissues. With the union of the cambial strips of the vascular bundles, a continuous ring of cambium is developed which cuts off secondary xylem towards inside and secondary phloem towards outside. Due to increase in the girth of stem, the continuity of the epidermis is broken at various places. The function of protecting the inner tissues is taken up by some of the cells or collenchyma, converting themselves into cork cambium or phellogem, which cuts off more cells towards outside and a few cells towards inside. Those cells

that are formed towards outside form the cork or phellum and those that are formed towards inside form the secondary cortex or phelloderm. The phellogen with phellem and phelloderm is the periderm. The removal of the periderm with the bud is the main operation of bud-grafting. The cork cambium at some places, where the epidermis is broken, do not form the cork cells. Instead a group of powdery cells known as complimentary cells are formed. The structure is called the lenticel which facilitates exchange processes (Figure 27). The secondary cortex consists of parenchyma cells, traversed by many laticiferous cells. A group of sclerenchyma cells are also found in the cortex. The secondary phloem consists of well-developed sieve tubes to conduct the food material. The cambium in between the phloem and the xylem cuts cells regularly, adding more of secondary tissues year by year. Due to increase in the girth of the stem, the primary xylem is pushed to the centre which is ultimately crushed to form the hard wood. Depending upon the requirement of the water in different seasons, the cambium cuts off xylem cells of high and narrow calibre. The amount of wood produced in one year is the annual ring. For instance, in the winter and autumn seasons, the plants under temperate climate, shed their leaves and practically there will be dormant condition. During this period the xylem cells of narrow calibre are formed. But during spring, as the plants put forth a large number of branches and leaves, it requires more water to be absorbed from the soil. Therefore, the xylem of high calibre are produced (Figures 28a and 28b). The shoots with active cambium, are selected for propagation through cuttings or scions in grafting.

4.3 Anatomy of leaf:

4.3.1 **Anatomy of the Petiole:** The internal structure of the petiole of mulberry is like the primary tissues of the stem. The epidermis is single layered. Some of the cells are drawn into epidermal hairs in certain species. Below the epidermis, there is a supporting tissue of four to five layers of collenchyma cells. The ground parenchyma is like the cortex of the stem. The vascular bundles are collateral and scattered in the ground parenchyma in a circular manner in early stages. The phloem is oriented towards the periphery of the petiole (Figure 29).

4.3.2 **Anatomy of leaf blade:** The leaves are dorsiventral with reticulate venation. The upper epidermis consists of a single layer of tabular shaped cells closely arranged without intercellular space. However, the continuity is broken at certain places due to enlargement of the cells in the form of idioblasts. The outer walls are cutinized and a layer of cuticle is found. The thickness of the cuticle varies with mulberry variety. The thickness of the cuticle, number of idioblasts and thickness of the blade have a significant role in determining the feeding quality of leaf. Those with thinner cuticle, thinner leaf blade and fewer number of cystoliths are more palatable to silkworms (Melikyan and Babyan, 1971).

The idioblasts contain deposits of calcium carbonate (Katsumata, 1970). The shape of the idioblast is taken into consideration in classifying the different species of *Morus*. Those with narrow beak are grouped under "Dolichocystolithiae" group as in *Morus bombycis, M. australis* and *M. kagayamae* and those with broken beak are grouped under "Brachycystolithiae" group as in *Morus latifolia, M. alba* and *M. tiliaefolia* (Hotta, 1932). The size of the idioblast varies with the maturity of the leaf. Generally the maximum sized idioblast is taken into consideration (Figure 30). The idioblasts connected with vein are bigger than those unconnected with vein. Those which are not connected with vein are taken for classification (Figure 31).

The lower epidermis is much like the upper epidermis but with a thinner cuticle and stomata. Idioblasts are absent. Number of stomata per unit area of the leaf, size of the stoma and the size of the guard cells varies from diploid to polyploids (Figure 33).

The palisade parenchyma is usually a single layer of closely packed, elongate-prismatic shaped cells with their long axes at right angles to the upper epidermis, with numerous chloroplasts along the inner sides. Sometimes, as in Goshoerami, more than one layer is seen.

Spongy parenchyma consists of isodiametric or slightly elongated cells with fewer chloroplasts. The cells are loosely packed leaving large inter-cellular space and respiratory cavities near the stoma.

Vascular bundle consists of xylem and phloem (Figures 32a and 32b). Xylem is arranged towards the upper epidermis and phloem towards the lower epidermis with a bundle sheath of a single layer of compactly arranged colourless parenchymatous cells extending on one or either side of the bundle towards epidermis in almost all the prominent veins (Esau, 1953). The bigger vascular bundles found to have a sclerenchyma sheath within the bundle sheath, covering completely the vascular bundle or as patches on one or both of the sides.

4.4 Embryology:

4.4.1 **Microsporogenesis:** (Figure 34) Anther to begin with, is a mass of meristematic cells. A row of three hypodermal cells forms the Archesporial cells. These cells on pericinal division give rise to primary parietal cells and primary sporogenous cells. Primary parietal cells by repeated divisions form a thick wall, usually of three to four layers. The innermost layer forms a nutritive jacket called tapetum. The tapetal cells contain a single nucleus in the beginning, but later they become multi-nucleate. The primary sporogenous cells divide a number of times to form pollen mother cells. At early diakinesis the 28 chromosomes which form 14 pairs are found distributed along the periphery of the nucleus. The nucleus has a peripheral position. Separation of bivalents is fairly regular. Usually one ring bivalent with two terminal chiasmata is formed while the rest are all rod-shaped with single terminal chiasma. Two rod bivalents are attached to the nucleolus.

During the metaphase all the bivalents are arranged at the equilatorial plate with the bipolar spindles. The characteristic feature of metaphase is the association or approximation of the separate bivalents. This secondary association is prevalent in a majority of the pollen mother cells with variable nucleus of bivalents. Secondary association is maintained even in anaphase-I and metaphase-II. Anaphase is quite normal and disjunction of chromosomes is uniform. After anaphase the chromosomes organise themselves into the interphasic nuclei. Now the nucleus makes its appearance at both the interphasic nuclei. No partition wall is formed at this stage. When the homotypic division sets in, the interphasic nuclei at either pole lose their nuclear membrane and nucleoli. At this stage, the haploid chromosomes are arranged at the poles and the secondary association of the univalents is also observed. In metaphase-II chromosomes undergo normal disjunction and four telophasic nuclei are formed with haploid number of chromosomes. Simultaneous furrowing takes place from the periphery towards the centre during the formation of tetrad. The tetrads are usually either isobilateral or tatrahedral. Pollen grains at the time of shedding, are two celled and 98 percent of them are fertile.

4.4.2 **Megasporogenesis:** (Figure 35) The megasporangium or the ovule arises as an outgrowth of meristematic cells on placenta. This soon differentiates into funicle and nucellus. As development proceeds, one or two ring-like outgrowths envelope round the nucellus except at the top, forming the micropyle. From the nucellar primordium a single cell differentiates as primary archesporial cell. This cuts off a primary parietal cell to the outside and the megaspore mother cell to the inside. The primary parietal cell by repeated divisions forms the wall. The megaspore mother cell undergoes the heterotypic division as a result of which a dyad is formed. The cells of the dyad undergo homotypic divisions to give rise to a linear tetrad of which only the lowermost forms the uninucleate embryosac while the rest degenerate. The mature embryosac is pear-shaped. Two synergids and a round egg cell constitute the egg apparatus at the micropylar region. The fusion of the polar nuclei takes place before fertilization. Primary endosperm nucleus lies in the middle of the embryosac. The embryosac is normal monosporic polygonum type.

4.4.3 **Male Gametophyte:** Each pollen grain divides asymmetrically into a large or tube cell and a small generative cell. Pollen grains are bicelled at the time of shedding.

4.4.4 **Female Gametophyte:** The functional megaspore undergoes three successive mitotic divisions forming eight nucleate embryosac. The embryosac is pear–shaped. These eight nuclei lie in two groups of four each at two poles of the embryosac. One nucleus from each pole travels to the centre and fuse forming the primary endosperm nucleus. Three cells at the micropylar region form the egg apparatus. The centrally placed round cell is the egg and the adjacent cells become large synergids. The tree cells at the chalazal end form the antipodal cells which perish after fertilization.

4.4.5 **Fertilization:** After pollination is effected, the pollen grains germinate on the stigma. The rate of growth of pollen tube is generally influenced by environmental conditions, especially temperature. Pollen grains germinate under artificial conditions if grown on the surface of sucrose water or sucrose agar (about 1 percent to 5 percent in water). The most favourable concentration is usually in the range of 5 percent to 20 percent. It is reported that boron exerts a favourable influence on the germination of pollen grains. Prolongation of the life of pollen is often an important consideration in certain breeding problems. The pollen grain has two layers, the outer exine and the inner intine. The intine grows into a pollen tube through one of the germ–pores at the unthickened region of the exine. The nucleus of the pollen grain divides into a generative nucleus and a tube nucleus, at the time of shedding. On the stigmatic surface the generatial nucleus divides to form two male gametes or cells while the tube vegetative nucleus disorganizes.

The pollen tube carrying the two male gametes enters the micropyle and reaches the embryosac. The tip of the pollen tube degenerates and one of the male gametes unites with the primary endosperm nucleus. The other gamete fuses with the egg. This is the actual fertilization. As a result of fertilization, the egg develops into an embryo, integuments into seed coats, primary endosperm nucleus into an endosperm, ovule into seed, the ovary into fruit and the funicle into a seed stalk or sear, left by the stalk as hilum on the seed.

4.4.6 **Fruit:** The fruit of mulberry is a multiple one, as all the flowers of the inflorescence give rise to a single fruit. The inflorescence axis and the perinth parts become persistent and fleshy (Figures 36a and 36b). As the individual fruitlets fuse together with the fleshy peduncle, it is described as sorossis. Due to the act of fertilization the perianth leaves of the female flower also get stimulated, become succulent with a large quantity of juicy material and contribute to the formation of fruit. Thus, the individual berries of the sorossis of mulberry are described as pseudo–carps or false fruits. Usually fruits are observed in south India in two seasons in a year — during November–December and June–July. The fruit is green but changes to purplish through various shades of pink, red,etc., due to a certain water soluble pigment contained in the juice. In certain species the fruits remain creamy white and very sweet, perhaps attributable to higher concentration of sugars. The ripening of the fruit can also be hastened by chemical means without affecting the seed inside.

The fruits contain seeds but this is not invariably true. Seedless fruits are also of common occurrence in certain polyploid species like *M. nigra* and *M. latifolia*. This condition of seedlessness is called parthenocarpy. Even if there are seeds in such parthenocarpic fruits, they are without embryos. Parthenocarpy may be of natural occurrence or may be induced by artificial means by spraying certain types of hormones called auxins.

In natural parthenocarpy either pollination does not take place or is ineffective in bringing out fertilization and seed development. If the pollen grains happen to grow only up to the base of the style so as to permit chemical diffusion but not fertilization the resulting fruit is devoid of seed. If the stigmas of the female flowers are pollinated with immature, overmature or incompatible pollen, it results into parthenocarpy.

In some species which are naturally parthenocarpic the ovaries contain enough auxin to promote growth without fertilization. In other plants which do not contain the auxin in sufficient quantity it must therefore be augmented by pollination and fertilization or by pollination alone or by external application of the requisite growth promoting substance. Trees bearing parthenocarpic fruits are generally cultivated for their edible fruits. The fruits of *M. alba* are eaten fresh or made into juice, stews and tarts. They may be squashed and fermented to yield spiritias liquor. Analysis of the fruit shows the following constituents: moisture 87.5 percent, protein 1.5 percent, fat 0.4 percent,carbohydrates 8.3 per cent, fibre 1.4 percent, and minerals 9 percent; calcium 80 mg, phosphorous 40 mg, iron 1.9 mg/ 100 gr, carotene as vitamin A 1741, thiamine 9, nicotinic acid 0.8 mg, riboflavin 184 mg, ascorbic acid 13mg/ 100gr. The fruits contain a flavonoid, possibly eriodictyol.

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Chapter 5

CYTOGENETICS AND BREEDING

5.1 **Cytology:** Most of the species of *Morus* are diploid having 28 chromosomes (Figures 38a, 38b, 38c, 38d and 38e), but a few species like *Morus* tiliaefolia, *M. cathyana* and *M. nigra* are polyploids (Figure 37). *Morus laevigata* grown mostly in eastern Himalayas in India is a natural tetraploid. Many polyploid varieties, specially triploids, are extensively cultivated in the northern parts of Japan and are noted for their resistance to cold temperatures and diseases. They are rich in vegetative growth and the quality of leaves is superior to those of diploids. Triploids are produced by crossing diploids and artificially induced tetraploids. Tetraploids serve as a good breeding material in addition to their use for silkworm rearing.

Tahara (1910) had studied the cytology of some of the species and garden varieties of mulberry in Japan. Osawa (1920) determined the somatic and meiotic numbers of chromosomes in seven species and a number of commonly cultivated varieties of *Morus bombycis* koidz., *M. multicaulis* Perr. and triploid mutants in mulberry. Sinoto (1929) studied the cytology of dioecious plants of *Morus bombycis* and reported the unequal parts of chromosomes referred to as sex chromosomes. Janaki Ammal (1948) solved the genetic puzzle of existence of the highest polyploid speices of mulberry *Morus nigra,* 2n=308=22n. surrounded by diploids with the discovery of *Morus cathyana* (2n=56, 84 and 112) of Central China. Polysomaty is of common occurrence. Das (1963) reported the polyploid and aneuploid numbers in *Morus multicaulis* Perr. and in the strains, China White–1, China White–6, and Mandalaya, of *Morus alba.* The meotic division of *Morus laevigata* shows peculiarities like presence of multivalents and laggers, irregular separation of chromosomes and unequal number of chromosomes.

Morus tiliaefolia Makino is a hexaploid and tetra hybrids were produced when crossed with diploid females of *Morus bombycis, Morus alba* and *Morus 1how.* The somatic chromosomes of certain species and cultivated varieties are given below:

Chromosome numbers in mulberry:

Morux X	14	Microplyla	28
Morus acidosa	28	Multicaulis	28
Atropurpuva	28	Rubra (red mulberry)	28
Bombycis	28	*Serrata*	28
Cordatifelia	28	*Alba* (white mulberry var. Makada (3X)	
Indica silk mulberry	28	(Atropurpurea x Alba)	42
Kagayamae	28	Cathyana	56, 84, 112
Lavigata	28	Nigra black mulberry	308

Chromosome numbers in mulberry varieties:

Enshutakasoke	42	Kairyo–roso	28
Goshoerami	42	Cattaeneo	28
Ichihei	42	Kosen	28
Karyo–nezumigaeshi	28	Obowase	42

Sematso	28	Berhampore	28
Tago–wase	28	Autotetraplod	56
Local Variety	28	*Morus multicaulis* var. Sannish	28
Kanva–2	28		

In India steps are being made to reduce cost of production by adopting various agronomical practices and introducing superior and economic strains of mulberry. Earlier it was thought that introduction of exotic varieties, specially from Japan, might reduce the cost of production. Accordingly, some improved varieties of mulberry from Japan such as Kosen, Gosho–erami, Roso and Kairyo–nezumigaeshi, were imported for direct introduction into the field. These Japanese varieties were first directly introduced in Kashmir, where the climatic conditions are similar to those of Japan. But experience has shown that under tropical climatic conditions of multivoltine areas, these Japanese varieties cannot totally replace the indigenous varieties because of the difficulty in adaptation to indigenous cultural practices. As early as in 1958 Tazima suggested the selection from local varieties of mulberry which can give enough yield as well as good quality leaves, as such local varieties are already acclimatized to local conditions. He further suggested that attention should be made for crossing of exotic varieties of mulberry with local varieties and selection from promising specimens from F1 population for further trials. Accordingly, a suitable research programme was drawn and superior strains from seedlings and from hybrid progenies have been evolved in India.

5.2 **Genetic improvement:** Improved strains of mulberry are obtained by adopting the conventional breeding methods followed in other agricultural or horticultural plants. They are (i) selection, (ii) hybridization and selection, (iii) polyploidy breeding and (iv) mutation breeding.

5.2.1 **Selection:** Mulberry is a highly heterozygous plant which is open for cross fertilization. Therefore, the seeds that are formed through open pollination are natural hybrids. Seedling population from such seeds provide wider chances for selection of superior types whose characters are perpetuated through vegetative propagation. Generally, the population thus obtained is a mixture of several clones. Each clone is heterozygous though homogeneous and the same genotype is maintained due to vegetative propagation. The variations between different clones are due to heredity.

5.2.1a **Method of selection:** Seeds collected from different plants of different areas are planted in small seed beds or in earthern pots. When they attain a height of 15 or 30 cm they are transplanted in rows of 90 cm by 60 cm. Preliminary selection on visual observation for the desirable characters is made. Cuttings from such selected strains are prepared and planted in a progeny row. Preliminary and final leaf yield trials are conducted by adopting suitable statistical design. Coordinated rearing experiments are also conducted simultaneously to establish the superiority in leaf quality.

5.2.1b **Characters taken for selection:**

1. The selected plant should be able to strike roots when propagated through cuttings.
2. Greater and quicker percentage of sprouting of vegetative bends.
3. Height of the plant.
4. Branching habit.
5. Shortest internodal length.
6. Shape and size of the lamina.
7. Succulency of leaf.

8. Palatability to silkworms.
9. Leaf yield per unit area.
10. Response to indigenous cultural practices.

The seedling selection for the improvement in mulberry is followed in all the sericultural countries of the world. Japanese varieties such as Ichehai, Kamraso, Kosen and Mijuchi are the selected strains from the seedlings of Roso variety. In India, the variety Kanva–2 was selected from the seedlings of Mysore local. This improved strain yields 25 percent increase over the existing local variety. It responds well to the manurial inputs and cultural practices with good quality of leaf far superior to the local variety for feeding the silkworms. This variety is gradually replacing the local strain.

5.2.2. **Hybridization and selection:** The purpose of breeding mulberry is to develop or evolve varieties that are efficient in nutrients, that gives the greatest return of high quality leaf per unit area, in relation to cost and ease of production. It is also of importance to evolve varieties that can withstand extreme conditions and resist the pathogenic organisms and insect pests. The desirable characters which are valuable are found scattered in different species, varieties and races. A single type combining all the desirable characteristics is to be evolved by repeated hybridization.

5.2.2a **Techniques of hybridization:** The technique of hybridization mainly consists of processes to ensure the pollen and stigma of known plants being brought together.

5.2.2b **Appliances necessary for breeding**

1. Hand lens.
2. Small camel hair brush.
3. Fine pointed or curved scissors.
4. Cellophane paper covers or bags to cover the male and female catkins.
5. Specimen tubes and petri dishes to collect and store the pollen from male flowers.
6. Mounted needles.
7. Stakes and field labels for marking the selected parents.
8. Field labels for marking the crossed flowers.
9. Field stool.
10. Field records.
11. Refrigerator to store the pollen, if necessary in case of protandry.

5.2.2c **Collection and maintenance of Germplasm:** The starting point of any breeding programme is the collection of as many varieties of mulberry as possible both exotic and indigenous, cultivated and wild, followed by the evaluation of the material for desirable characters.

5.2.2d **Selection of parents:** Based on the above studies, male and female parents are to be selected. The hybridization work may be carried out on branches of grown up trees. Alternately the cuttings from either parents are planted separately in earthern pots filled with sand at least two months earlier to the commencement of breeding (Figure 39). It is not difficult in tropical countries to carry out the operations throughout the year as and when the flowers bloom. But, there is considerable difficulty experienced in countries with temperate climates. In Japan, Sugiyama (1953) devised a simple method of conducting hybridization work in the field throughout the year with the use of cuttings. One year old cut shoots of which the crowns are severed off in winter or early spring are stored at 2–5^{0}C. These shoots are taken out whenever necessary and cut into pieces of 15 cm. length with three or more buds. The cuttings are planted in the sand in a pot, wherein a 25^{0}C temperature is maintained. Buds sprout within two weeks and the flowers bloom.

5.2.2e **Anthesis:** A detailed study of either parents is made so as to find out when the anther sacs burst open, viability period of pollen, etc. in the male catkin and the receptivity of the stigma in the female flower. In India, Das *et al* (1970) studied the anthesis in ten mulberry varieties viz. *Morus alba* var. *mandalay, M. alba* var. *philippine, M. alba* var. *blackcherry, M. alba* var. *english black, Morus indica* var. *assamjati, M. indica* var. *white badana, M. lhov* var. *roso, M. latifolia* var. *kosen, M. rotundiloba* and *M. laevigata* and reported that the blooming times of flowers vary from January to March. The number of inflorescence from the bud varied from one to six and the period taken for complete emergence of the inflorescence varied from one to four days. The receptivity of the female flower continued for seven to ten days, in the absence of pollen. The peak period of dehiscence of anthers is between 11.00 A.M. to 1.00 P.M. in most of the varieties.

5.2.2f **Collection of pollen:** When the male flowers bloom, pollen is collected from them with the help of a small camel hair brush, into small specimen tubes. In case the male flowers mature earlier than female, it is necessary to collect the pollen and preserve it till the stigma becomes receptive. Male catkins with pollen are collected in petri dishes and preserved in dessicators whose lower part is filled with anhydrous calcium chloride and kept at 0–10^0 (Das and Katagiri 1868). Pollen grains stored as above remain viable for about two weeks.

5.2.2g **Artificial pollination:** The pollen thus collected from the male flower is dusted on the stigmatic surface of the female flowers by removing the cellophane bags and covering them again after dusting till the stigma is no more receptive or has lost its function. The removal of the cover of the female flower to dust the pollen grain involves risk. To avoid this difficulty a "pollen gun" is commonly used (Figure 40a) in Japan to shed the pollen grains on the stigmatic surface without removing the bag. The pollen gun consists of two parts, a glass container (a) fitted with a rubber cork with outlet and inlet glass tubes and a fine sprayer. One end of the inlet tube (B) is fixed to the fine sprayer and the end of the outlet tube is drawn into a fine nozzle (A). A pinch cock is attached to the rubber tube joining with the inlet tube of the container. Air is sucked in by pressing the end (D) of the gun which inflates the bladder (C). The pressure of the air is released uniformly by pressing the pinch cock (B) which ultimately passes through (A) and goes out through the outlet nozzle (a). A fine thread net limits the maximum elasticity of the bladder (C) and protects it from puncturing during use.

Mukerjee (1965) conducted hybridization work by using the pollen gun in the following manner: Branches containing male flowers were collected from a male plant just before blossoming and were carried to a closed room in the field laboratory (with still air). The perianth of the male flower was separated by asceptic needle or forceps and the pollens were collected in a dry container. After each day's collection the container (A) with pollen were put inside a dessicator in a cool place. Pollination was carried out in the properly matured female species (previously bagged in the young stage) at the right time by the use of the pollen gun without removing the bags. Holes were pierced carefully by the fire nozzle, into the individual bags at two or three places depending upon the size of the bag and the pollens were dusted on the female inflorescence with the help of the pollinator. The holes were sealed with paper or an adhesive tape. The bags were removed after thirty days depending upon the variety.

The following details are to be recorded after crossing:

1. Details of the male parent.
2. Details of the female parent.
3. Date of crossing.
4. Date of picking the first crossed fruit.
5. Seasonal and geographical variations, if any.

The seeds are collected from the crossed fruits and subjected to purity tests.

5.2.3 **Breeding for disease resistance:** Mulberry, as any other commercial crop, is susceptible to the attack of various pathogens causing damage to the plantations. Powdery mildew disease caused by *Phyllactenia corylea* specially during rainy seasons is a problem to be solved at higher altitudes. As fungicides and insecticides cannot be sprayed on mulberry leaves without adversely affecting the silkworm feed quality, the only method is to breed varieties of mulberry resistant to the diseases and pests. The disease resistance quality is to be obtained in combination with other desirable characters of mulberry. The disease resistant types must be tested under artificial epidemics with the cooperation of a pathologist. Though the variety thus selected is resistant to diseases confined to a particular zone, it must also be studied under varied climatic conditions, for instance, *Morus multicaulis* var. Sannish–5 is resistant to Mildew in the U.S.S.R., but is susceptible to the attack in Karnataka.

5.2.4 **Breeding for drought resistance:** Resistance to drought conditions is an important character to be associated with other desirable characters in tropical and semi–arid regions. In India, the rainfall is very low and monsoon is erratic and unpredictable. There are frequent occurrences of drought in semi–arid tropical regions and hence losses of crops are also frequent due to scarcity of water. In addition to the development of suitable farming technology evolution of drought resistant varieties would be desirable.

The water requirement of mulberry does not differ greatly from species to species or from variety to variety. The plant must be capable of absorbing water from soils of low mositure regime. Generally resistant plants should have well developed root systems, development of hydrophilic colloids to absorb and hold water by limibibition and adaptations that help lowering of transpiration. In this regard certain Japanese varieites have certain benefical characters such as thick cuticle, sometimes two layered epidermis and palisade parenchyma.

The breeding technique for this purpose is the same as for the other characteristics. Resistant types are to be isolated from the hybrid progenies and tested under varied climatic conditions and used in the field.

Likewise, frost resistance is a problem in temperate countries. Resistant types were produced in Japan and the U.S.S.R. by adopting the same techniques.

Since the parents differ widely in the characters because of their heterozygous and homogeneous nature, it is not desirable to go beyond the F1 generation as splitting of characters take place in the first generation. The promising individuals are selected and propagated through clones. High yielding strains of mulberry from inter–specific and inter–varietal crosses have been reported from different countries. *Morus indica* var. Assamabola x *M. alba* var. *Philippine* (Figure 40b), *M. alba* var. E*nglish black* x *M. latifolia* var. *Kosen* (Figure 41) are the best selected hybrid progenies from the Central Sericultural Research and Training Institute, Mysore (India). In Japan, Kokuso–20, Kokuso–21, and Kokuso–27 are obtained through artificial crossing over several years and from selection of seedlings obtained from a cross between Naganoma as female parent and Garyo, Shizo and Kairio as male parents, respectively. Das and Krishnaswami (1965) selected some promising strains from the hybrid progenies of *Morus indica* x *M. latifolia* var. *kosen, M. alba* var. *dudhiawhite* x *M latifolia* var. *kosen, M. rotundiloba* x *M latifolia* var. *kosen, M. multicaulis* x *M. alba* var. *blackcherry, M. indica 'X'* x *M. alba* var. *mandalay, M. indica* var. *berhampore–1* x *M. alba* var. *cattaneo, M. indica* var. *laciniata* x *M. 1hov* var. *roso* from the *Central Sericultural Research Station,* Berhampore, West Bengal, India. Mulo'v (1968) obtained a high yielding variety "Harkov–8" from a cross between *Morus alba* x *M. multicaulis* in the U.S.S.R. In addition to the superiority of leaf yield, it has good frost resistance and resistance to *Cylindrosporium* and root neck diseases.

5.2.3 **Polyploidy Breeding:** Majority of the species of mulberry are diploids. However, certain species like *Morus nigra* and *Morus cathyana* are polyploids. Polyploidy in mulberry, either natural or artificial, has a great economic value in the evolution of superior strains. Most mulberry breeders all over the world have succeeded in inducing polyploids through colchicine and promising hybrids have been obtained from the induced polyploids and diploids.

5.2.4 **Treatment with colchicine:** Seeds, seedlings and vegetative buds are used for colchicine treatment. The chemical can be applied adopting any of the methods given below:

1. Twigs are immersed with colchicine solution of various concentrations for different durations.

2. Solutions of colchicine in agar–agar may be applied to growing buds: the solution is warmed in a liquid state before application.

3. The colchicine solution is allowed to fall on the growing bud at proper intervals.

4. The chemical may be applied as a paste in lanolin.

5. Germinating seeds may be soaked in colchicine solution of varying concentrations for varying durations.

Colchiploids have shown all the symptoms of polyploids such as bigger stomatal size, dark green coloured leaves (Figure 42), delayed flowering, etc. The polyploid forms exhibit characters which are morphologically, physiologically and genetically varied. The stem of the polyploid is usually stouter and thicker and the leaves are longer, broader and thicker with a dark green colour. The flowers and seeds are bigger than diploids.Polyploidy leads to new physiological properties. They have reserves of genes which can mutate in any direction without any deleterious effect on the organism.

Kedaranathan and Laxmikanthan (1966) succeeded in inducing auto tetraploid with *Morus alba* with application of ½ percent colchicine to the vegetative buds. Abdullaev (1963) produced the high yielding variety of autotetraploid mulberry, "Kol–tut", with the application of colchicine and X–ray irradiation. Tojyo (1966) also succeeded in inducing auto–tetraploids in Kairio–nezumigaeshi and Kenmochi with 0.4 percent colchicine. Sastry *et al*(1968) reported the success of inducing polyploidy in Kanva–2 through the application of 0.4 percent colchicine. Das *et al* (1970) produced tetraploids of mulberry with colchicine treatments to seedlings and buds.

The polyploids are superior to diploids in most respects. Seki and Oshikana (1957) conducted feeding trials with leaves of diploids, triploids and tetraploids. It was found that when silkworms were fed with the polyploid leaves, they showed heavy larval weight, a good cocoon harvest, a longer filament length, the proper denier of cocoon fibre for the raw silk and higher production of eggs. Abdullaev (1963) also reported that the leaves obtained from polyploids are of better quality for silkworm feeding than most of the diploid varieities. Alizada and Akhundova (1968) made a comparative study of the nucleic acids of polyploids and diploids and triploids and tetraploids. In the young leaves of tetraploids, the Desoxyribonucleic acid (DNA) content was twice that of diploids of the same variety and DNA content per cell of the tetraploid was three times that of a diploid cell. The ribonucleic acid (RNA) content increased correspondingly by 1.5 times. In all cases, both the relative and the absolute content of nucleic acid in the mature leaves was greater in the diploids forms than the triploid and tetraploid forms.

Plaksina and Dzafrav (1968) made a thorough study of the nutritive contents of diploids, triploids, tetraploids and dodecaploids. Tetraploids contain more protein nitrogen than the diploids throughout the vegetative period. The soluble carbohydrate content in spring in the leaves of 4 N was lower than in the 3 N or 2 N, but in summer it increases to the same level as triploids and diploids.

Realizing the importance of nutritive superiority of polyploids, many crosses were made to produce triploids. Several high yielding triploids with good quality leaves were produced all over the world through hybridization between the diploids and tetraploid varieites. A comparison of diploids with polyploids indicates: (1) autotetraploids seem to be comparatively stronger than diploids; (2) there will not be reversal of sexes; (3) in autotetraploid, though there is an initial delay in sprouting, subsequent growth rate is accelerated; (4) in autotetraploid, the green weight of leaves is heavier; (5) the polyploids show slow evaporation; and (6) the best polyploids were obtained by breeding and selection at the tetraploid level.

5.2.5 **Mutation Breeding:** Since mulberry is a highly heterozygous plant there is great scope to introduce variability through conventional breeding methods. Inducing mutations artificially might also be beneficial to eliminate certain undesirable characters. Such beneficial mutant characters can successfully be perpetuated through clonal propagation, without disturbing the genetic balance of the original variety. Mutations in mulberry are spontaneous or induced. Many varieties used to silkworm rearing are believed to have arisen through spontaneous bud mutations. Owada (1963) reported the occurrence of spontaneous mutation with unlobed leaf, in the field planted with Kairio–nezumigaeshi of lobed leaves. Jumonji, Ichinose and Shukakuichi are also obtained through bud sprouts.

5.2.5a **Characters of mutation:**

1. Mutations differ from the parental type in one or more of morphological, physiological or biochemical traits.

2. Most of the mutations are recessive and they are carried along in heteroxygous condition for several generations, being a cross fertilized plant.

3. Different mutations at the same races give rise to the multiple allelic series.

4. Any particular change in the gene is usually recurrent.

5. Mutations are often reversible.

5.2.5b **Induced Mutations:** Mutations can be induced through irradiations (both ionizing such X–rays, B–rays, radioisotopes, r–rays and fast neutrons, and non–izonizing ultra violet rays) and also chemicals. Ionizing radiations of shorter wave lengths penetrate deep into the tissues and bring about mutations, whereas a non–ionizing radiation can produce mutations in softer tissues like pollen grains. Radiation acts on the composition of the gene molecule either by ejection or excitation of electrons in the atom.

Various plant parts are used to induce mutation, such as seeds, young seedlings, and most commonly the buds. The small–scale buds on either side of the main bud are ideal to induce mutation because they are still immature with few meristematic cells (Hazame, 1967). When the main branch is pruned by "cut–back method" these small buds are forced to sprout and as a result a fully mutated shoot could be obtained.

5.2.5c **Mutagen dosage and frequency of mutation:** Das (1970) exposed the dry seeds of *Morus alba* var. *ichinose* with 4.5 percent moisture content to gamma rays (60c0 source) at 2.5 kr to 15 kr at the dose rate of 5 kr per hour. The lethal dose for mulberry seedlings of Ichinose variety is 10 kr. Kuchkrov (1965) on the other hand reported that valuable mutants were obtained by irradiating the seeds of *Morus alba* at 5 to 33 kr. Particularly, doses of 25 kr and 35 kr were effective in inducing mutations.

Katagiri (1970) reported that there are varietal differences in mutation rate and mutation spectrum after actue gamma ray irradiation. Dormant buds of one year saplings of nine varieties, viz., No. 17, No. 1021, No. 2010, No. 3017, Atsumamidori, Kokuso–70, Vasemidori, Kokuso–21 and Kokuso–27 exposed to acute gamma rays at 7.5 kr with 5 kr per hour and he observed nine different types of mutations such as elongated leaves, leaf margins curved, variegated leaves, entire leaf, white margined leaves, centrally pale green leaf, multilobed leaves, small leaves and completely yellow leaves. Varieties with higher mutation rate result in wider range of spectrum and varieties with lower mutation rate show narrower mutation rate.

Sugiyama and Tojyo (1962) treated the cuttings of Kenmochi (female) and Kairio–nezumigaeshi with the object of breeding beneficial mutants. The cuttings were exposed to 2.5 to 10 kr from 60c0 and also with 32p on flower buds. The cross pollination was done between treated x treated; untreated x treated; treated x untreated and untreated x untreated. Higher dosages caused bud injury to such an extent that the reproductive tissues were damaged. Pollen grains were of abnormal nature, with variable sizes and fertility. Seeds from among the treated batches germinated. No abnormalities were noticed with internal irradiation of 32p in flowering or seed setting, except in the growth in younger stages in the nursery.

In Japan, Hazama (1968) obtained a beneficial mutant of Kairio–nezumagaeshi bearing unlobed leaves from lobed leaves due to acute gamma radiation of 5 to 10 kr at the dose rate of 5 kr per hour. One sapling with 5 kr produced two branches of which one was with unlobed leaves and the other was completely lobed. The leaf thickness was 7 percent more than the original. The inter–nodal length was 20 percent shorter than the original. Twelve percent increase in the yield was also noticed. This is being popularized in Japan.

The genetical basis of bud mutation in mulberry is not clearly understood. But the entire mutation found in Kairio–nezumigaeshi seems to be the production of rececive entire allels, owing to the mutation of dominant lobed gene, or the deletion of chromosomes, including lobed gene, because these varieties have heterogenic state for lobed gene.

5.2.6 **Chemical mutagenesis in mulberry:** Beneficial mutants are also obtained in mulberry with the application of various mutagenic chemicals.

Mutagenic chemicals:

1. Ethyl Methane Sulphonate (E.M.S.)
2. Methyl Methane Sulphonate (M.M.S.)
3. 1–4 Dimethyl sulphonoxy butane
4. Diethyl sulphate
5. Malic hydrazide
6. 8–Ethoxy–caffine
7. 5–Brom Uracil
8. Hydraxylanine.

Ethyl methane sulphonate is particularly effective in giving a wider spectrum of morphological characters than physical radiation. Work on chemical mutagenesis in mulberry was carried out at the Central Sericultural Research and Training Institute, Mysore (India). The seeds of a true breeding monocious Berhampore variety were treated with aqueous solution of EMS in different concentrations (0.1 percent, 0.15 percent, 0.3 percent, 0.45 percent, and 0.6 percent) for six hours, 12 hours and 24 hours at 5°C and 25°C. The maximum seedling survival was reported in the batch of 12 hours duration at 5°C. Beneficial mutant strains S.30, S.36, S.41 and S.54 were isolated in M3 generation. These strains are superior to Kanva 2 (Figure 43a), not only in the leaf yield but also in leaf quality (Sastry *et al,* 1974). The best among these strains is S 54 which is being introduced into the field for cultivation by the farmers (Figure 43b).

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Part III

CULTIVATION OF MULBERRY

Chapter 6

PROPAGATION

Mulberry is propagated either through seeds or vegetatively. The latter is the most common method of propagation because of various advantages like maintenance of particular characters of the plant, relative speed in raising saplings in large numbers for plantation, the adaptability to a particular habitat, to develop resistance to pests and diseases and to modify the growth of plant. Propagation through seeds has got certain limitations. Triploid plants cannot be propagated due to their inability to produce viable seeds. It is not possible to reproduce true to the type from a seed due to biparental origin. Different countries depending upon climatic and soil conditions follow different modes of vegetative propagation. Hamada (1958) described the various methods followed in Japan. They include (i) bark grafting (Fukurotsugi), (ii) veneer grafting (Kiritsugi), (iii) simple layers (Magedori), (iv) continuous layers (Shumokudori), (v) division (Shirodasmi,) hardwood cuttings (Kojyosashiki) and softwood cuttings (Shinshosashiki). Generally grafting is followed in places where temperature is 6^{0}C in March and more than 25^{0}C in July with rainfall of 175mm. Shirodasmi cuttage is popular in places of temperature less than 4^{0}C in March and lesser than 25^{0}C in July with rainfall lower than 175 mm. Propagation through hardwood cuttings is common in northern districts and through softwood cuttings in southern region of Japan (Taguchi 1971). In Italy (Lombardi, 1960) root grafting is the popular method of mutiplying the Japanese mulberry varieties like Kokuso–20, Koskuso–21 and Kokuso–27. Ullal (1964) in his study report on sericulture in the U.S.S.R. stated that the most common method of propagating mulberry is through root grafts in addition to raising seedlings. "In–situ grafting" is also being followed to quickly replace the old trees.

In India the most common method of propagating mulberry is through cuttings in multivoltine regions like Karnataka and West Bengal. Exotic varieties which do not come up by cuttings are propagated through root grafts. Many of the indigenous varieties and well acclimatized exotic varieties are propagated through cuttings.

Bud grafting (budding) is followed only when the scion material is scarce. Whenever a large mulberry plant is to be obtained in a shorter time than would be produced if started as a cutting, the method of layering is followed. This advantage is made use of in filling up the gaps formed due to failure of sprouting of certain cuttings planted in pits of established plantations.

In Univoltine areas like Kashmir, the mulberry is propagated through seedlings and the exotic varieties through root grafts. In India propagation of Japanese varieties of mulberry through cuttings on a field scale is still a problem.

6.1 **Seedling propagation:** Propagation through seeds is mainly to bring about a varied population for the purpose of selection and hybridization. Since mulberry flowers are open for cross pollination, the seeds thus collected are mainly used to obtain stock material for grafting.

6.1.1 **Preparation of seedling nursery:** An area preferably under shade is selected to raise seedling nursery in tropical countries. The soil is thoroughly prepared to a fine tilth. Equal quantities of red earth, sand and farm yard manure are applied. Seed beds of convenient size, i.e. 0.9 m. are made (Figure 44). Provision should be made to protect the young seedlings from excessive light and temperature.

6.1.2 **Sowing of seeds:** Seeds with viable embryos are soaked for a day in water to soften the hard testa for easy and successful germination. They are broadcast in seed beds or sown in holes drilled in a line or sown in a line with the help of a rope. The seeds should not be sown deeper than 2½ cm in the bed lest the germination may not take place or sometimes be delayed due to the non-availability of oxygen or excessive carbon dioxide or even both. The holes are then covered with soft earth. Water is applied through watering can gently to avoid splashing. Small quantity of insecticide can also be applied if necessary to protect from the attack of insects. Seed beds are protected from severe sun by covering them with mats made up of bamboo strips or plaited coconut leaves which are placed one foot above the nursery beds on pegs fixed around them.

6.1.3 **Germination of seeds:** Temperature and light have a marked effect on the germination of seeds (Figure 45). In Japan it is recorded that minimum of 18°C to 21°C, optimum 33°C to 36°C and maximum 36°C to 39°C for the germination of seeds. Seeds germinate better in bright light than in total darkness. The germination is delayed with lowering of temperature for instance six days at 33°C or 36°C, eight days at 30°C and ten days at 27°C. Coloured light of violet, bluish violet or indigo has an inhibiting action on sprouting resulting in poor germination. In Karnataka conditions seeds germinate after ten days.

Rao and Narayanan (1963) recorded 94 percent germination of three months stored seeds of *Morus indica* when treated with 50 ppm of gibberellic acid. Sometimes dormant seeds fail to germinate due to internal defects like impermeable and mechanically resistant seed coats, rudimentary and physiologically defective embryos. Such a dormancy, however, can be interrupted by scarification, low temperature and fluctuating temperature, as followed in other seeds.

6.1.4 **Seedlings:** When the seedlings attain 3.5 to 5 cms height, they are thinned by picking from dense areas and planted in thinner areas. Direct sunlight which is essential for young plants is allowed to fall on them during the cool hours of the day and on cloudy days. Transplanting of seedlings is done first after three months with a distance of 22.5 cm between them. They are allowed to grow for one to two years, when they are removed either to raise tree plantations or utilize the stock for grafting.

6.2 **Cutting:** In India propagation through cuttings is the most common method. It is restricted to varieties which are fully acclimatized to local conditions. Plants which conform to the qualities chosen for multiplication such as nutritious leaf, higher yield, quick growth, resistance to diseases and insect pests and drought resistance are selected.

6.2.1 **Preparation of the cutting:** Shoots of proper maturity and thickness with active and well developed buds are cut from the selected varieities. Cuttings taken from parts with high carbohydrate content root more readily and profusely than from a cutting selected from parts rich in nitrogen. Accordingly the portions of the shoot which are too tender at the top and over mature at the base are rejected. Generally cuttings taken from young seedlings root more rapidly and profusely than those taken from old and mature plants. Cuttings of 7 to 10 cm usually of pencil thickness with three or four active buds are prepared out of the central portion of the clone with the slanting cut. These cuttings are planted in the field directly or in nursery beds. When kept in nursery, all precautions should be observed in not allowing the cuttings to dry up. Convenient size nursery beds as in the case of seed beds are made and cuttings are planted in a slanting position at a distance of seven to fifteen cms (Figure 46). After two or three months, sprouted cuttings are transplanted into the field depending upon the type of plantation to be raised.

6.2.2 **Formation of roots:** Adventitious roots develop from the basal end of the cutting as also from the root anlages of the bud. The roots develop endogenously. Some of the cells of the parenchyma in between and outside the vascular bundles convert themselves into meristamatic cells giving rise to root initials: these root initials divide and redivide to produce the root primordium. Cell division continues and there will be a differentiation of root tip from each group. The vascular system develops in the new root primordium and becomes connected to the vascular bundle. The root tip grows outward and emerges at right angles to the stem through cortex and epidermis (Figure 47).

Simultaneously there will be a formation of callus tissue at the basal end of the cutting under favourable environmental conditions. It is an irregular mass of parenchyma cells in various stages of lignification. This callus growth arises from cells and adjacent phloem although various cells of cortex and medulla also contribute. The root development and callus formation occur simultaneously leading to the belief that the formation of callus is essential for root development. In reality, these two are entirely different phenomena though occuring simultaneously (Figure 48). Sometimes, roots develop even without callus from the nodes. Callus formation is sometimes beneficial in those varieties which are slow to root as it provides a protection layer thereby preventing the cutting from dessication and decay. Sometimes it interferes with the absorption of water by the cutting.

Although many species of tropical climate, root profusely through cuttings, there are certain temperate varieties which do not ordinarily produce roots such as Japanese varieties like Gosho–erami, K.N.G., Ichinose, etc. Root induction has been successfully done in these varieties with the application of requisite quantity of root hormones artificially.

6.2.3 **Artificial induction of rooting with growth regulators:** Those varieties which do not ordinarily produce roots from a cutting are induced to root with the application of requisite quantity of root hormones. The following are the chemicals generally used: however, the efficacy of the substances varies from species to species and from variety to variety:

1. Indole Acetic Acid;
2. Indole Butyric Acid;
3. L. Naphthalene Acetic Acid;
4. 2, 4 Dichlorophenoxy Acetic Acid;
5. 2, 4 Dichlorophenoxy Butyric Acid;
6. 2, 4,5 Trichlorophenoxy Butyric Acid;
7. 2, 4, 5 Trichlorophenoxy Propionic Acid;
8. 2, 4, 5 Trichlorophenoxy Butyric Acid;

and various other commercial products like rootone, seradix, etc.

Development of root primordium depends upon the relative amount of natural auxin present in the plant. Those varieites which do not root apparently contain less auxin. The growth regulators mentioned above, act like auxins when applied in small quantities and move upward in mass translocation through xylem when the bases of the cuttings are soaked in their solutions.

6.2.4 **Methods of application of root hormones to cuttings:** The object of treatment is to increase the percentage of cuttings which form roots, hasten the root initiation and increase the number of roots per cutting. Indole butyric acid and napthalene acetic acid are proved to be better in producing roots than others. There are various methods in which the chemicals could be applied such as (i) direct application of the powder, (ii) soaking the cuttings in dilute solutions, (iii) dipping the cuttings in concentrated solutions, and (iv) application as a paste in lanolin.

6.2.5 **Direct application of the chemical:** These regulators are commercially available in the form of powder mixed with talc. Mixtures in different concentrations are spread on thin alluminium foil or wax paper. Cuttings whose bases are evened and moistened with water are then dipped or rotated in the chemical and planted immediately in the cutting bed.

6.2.6 **Soaking the cuttings in dilute solutions:** Aqueous solutions of the chemical in different concentrations are prepared. Bundles of cuttings are immersed in the solution only one inch at the base for different durations and inserted into the rooting medium (Figure 49). During treatment, cuttings should be kept at room temperature but notplacedin the sun. (Approximately 100 ppm of Indole Acetic Acid is prepared by dissolving ¼ teaspoonful of pure crystal in a little quantity of ethenol and a gallon of water is added to it stirring thoroughly.)

6.2.7 **Dipping the cutting in concentrated solution:** A concentrated solution of the chemical is prepared in alcohol and the basal portions of the cuttings are dipped for a shorter duration and planted immediately in the rooting medium. (Approximately 100 ppm of Indole Acetic Acid is prepared by dissolving ¼ teaspoonful of the chemical in 3 1/3 fluid ounces of 50 percent alcohol.)

6.2.8 **Duration of treatment:** Duration of treatment has a considerable effect on the root formation in lower and higher concentrations. According to Tsudai and Honda (1971) similar effects on root formation were observed with N.A.A. when the cuttings were immersed for a longer time at lower concentrations and shorter time at higher concentrations. The range of time of immersion effecting root formation is wider at lower concentrations and narrower at higher concentrations. The range of time of immersion effective for root formation varied with concentration of N.A.A., i.e. ranges were from 12 hours to 48 hours at 150 ppm, from 6 hours to 30 hours at 300 ppm, from 3 hours to 18 hours at 500 ppm, from 30 minutes to 2 hours at 1000 ppm, from 5 minutes to 60 minutes at 2000 ppm, from 3 seconds to 30 minutes at 5000 ppm and from 3 seconds to 10 minutes at 7500 ppm.

6.2.9 **Application as lanolin paste:** Requisite growth regulator mixed with lanolin base and smeared round the basal portion of the cutting also induces rooting.

In India, Rao and Azeez Khan (1963) had succeeded in inducing rooting nearly 80 to 85 percent in Japanese varieties such as Kosen and Gosho Erami with the application of NAA, IAA, IBA and NAA + IAA in a lanolin base of 1 percent strength and direct application of Seradix and Rootone in the form of powder.

6.3 **Grafting:** Grafting consists of inserting a small branch of a plant into a rooted plant of the same or allied species in such a way as to bring about an organic union between the two and finally make them grow as one. The branch that is inserted is known as the scion and the plant to which the scion is inserted is called the stock. The scion grows with the help of nourishment supplied by the stock. The stock is generally of an indigenous variety which is well acclimatized to the local conditions. Grafting thus facilitates the propagation of a variety which has the desirable qualities and which cannot be propagated by other means. Exotic mulberry varieties are propagated by this method using root of the local mulberry as stock and shoot of the exotic variety as scion (Figure 50).

There are three types of grafting namely, shoot grafting, root grafting and bud grafting. All these methods are pretty popular throughout the temperate zones. In Japan the best season for grafting is the spring.

Selection of stock and scion is very important as the success depends upon their quality. The stock should be preferably got from a one or two years old seedling. The size of the stock should be either slightly bigger or at least of the same size as that of the scion. Shoots of one year old and medium size are used as scions. The middle parts, cutting away the top and basal portions, are selected. The leaves from these plants should not have been plucked during the previous year. In Japan these scions are stored before early spring, keeping them in a refrigerator at 5°C and burying them under wet rice bran or sand, covering with straw mat or digging a ditch in a cool place covering it with fine soil and straw mat enclosing the scions. In Japan the seedlings of *Morus latifolia* are generally used for stock. It is desirable to use such varieties which are strong, having a great resistance to the damages caused by diseases or insects and are vigorous in rooting. On both the stock and the scion a slanting cut should be made at both ends. The scion is well inserted in between the bark and wood of the stock. They are carefully placed under controlled climatic conditions and planted in the soil. The union between the stock and the scion will be established within two to three months.

6.3.1 **Anatomy of graft union:** When the scion is inserted into the stock, organic union is established between them by the formation of secondary vascular tissues. Hence the cambium layers of the stock and scion are brought in close contact with each other. In case the cambium layers do not match, the union is delayed. When they are extremely mismatched union may be prevented. Cell division occurs rapidly for the formation of callus tissue. Proper temperature preferably 20°C to 40°C is conducive to rapid cell growth. It is also of importance to maintain high humidity to prevent the thin walled turgid cells from dessication and death.

As a second step interlocking parenchyma cells (callus tissue) are produced from the stock and the scion. The parenchyma of the phloem rays and immature parts of the xylem rays produce new parenchyma cells filling the gaps between the stock and the scion. Thus the thin walled parenchyma cells serve the conduction of water and nutrients from both the components. This is the callus tissue whose surface layers get suberized and become bad conductors of heat.

Along the edges of the original strips of cambium,cells of the callus also convert into meristematic cells. These cambial cells grow inward across the callus till they meet. Thus a continuous ring of cambium is formed.

The newly formed cambium cuts off secondary xylem towards inside and secondary phloem towards outside along with the original cambium of the stock and the scion. These new vascular strands soon establish their connection with the original xylem and phloem.

The union between the stock and the scion is from the cells which develop after the actual graft has been made. There is no fusion of cells or cell contents. Cells produced by the stock and by the scion each maintain their own distinct identities (Figure 51).

There are different types of grafting followed in different countries:

i) Wedge and crown grafting;

ii) Whip grafting;

iii) Root grafting either ordinary type of "In Situ";

iv) Bud grafting.

6.3.2 **Wedge Grafting:** Wedge grafting is followed to renovate the old plant. The plant is pruned at a height of convenient level and incision is made at a cut surface in the form of letter "V". The basal end of the scion is also cut obliquely downward to fit in the incession made on the stock. The scion is inserted into the stock and the grafting wax or grafting clay is applied at the region of contact.

Grafting wax: A mixture of tallow part, bees wax one part and resin four parts, melted together and baked with a small dough under water.

Grafting clay: Clay two parts, cow dung one part and some finely chopped hay mixed with water.

6.3.3 **Crown grafting:** When more than one scion is inserted, it is called crown grafting.

6 3.4 **Whip grafting:** To a stock of about 1.2 to 2.5 cm thickness, sloping cut is given to a length of 3.5 to 5 cm. The scion of the same thickness is also cut in a similar way so as to fit in the stock exactly, it is inserted into the stock and tied firmly with soft fibre. The wound is then covered with grafting wax.

6.3.5 **Root grafting:** When the root is used as a stock instead of shoot the grafting is called root grafting. Mysore Local variety is used as a stock material. Root is selected to the thickness of 0.6 to 2.5 cm from a one year old seedling and cut into bits of 5 to 7.5 cm in length. The top end of the root bit is cut obliquely. The scion bit of four to five inches long with two to three active buds are prepared. The basal end of the scion bit is cut obliquely and inserted at the pointed end of the stock between the wood and the bark (Figures 52a and 52b). The bark at the pointed end of the scion which goes inside the bark of the root is removed before insertion in such a way that the cambial layers of stock and scion are in close proximity with each other. Organic fusion is formed between the stock and the scion, and the plant having the characters of the scion is developed (Figure 53). As bandaging is not done, in this case, this type of grafting is very economical for multiplication.

The advantages claimed in this method are (i) percentage of success is more in this type of grafting, (ii) an individual can prepare 800 to 1000 grafts in eight hours, (iii) out of a two year old seedling, five to six stocks can be had and therefore five to six grafts can be prepared, thereby cost of labour is minimized.

6.3.6 **"In Situ" grafting:** In this type of grafting, the seedling which is used as stock is cut below the ground level including the transitional level and the grafting is done as in the case of root grafts but without disturbing the root from its original place in the soil. Though a more vigorous plant is obtained in this case, only one graft is developed from a seedling. While making "In Situ" grafting, it is necessary to take proper care in cutting the root below the transitional zone as otherwise there will be chances of sprouting from the region of the local stock.

6.3.7 **Bud grafting** (Budding): This method is followed only when the scion material is scarce. Bud grafting involves removal of only one bud and a small section of the bark without wood and grafting it to another clone. Since the physiological processes are the same as in grafting, it is called bud grafting or budding. The bud piece usually consists of the periderm, cortex and phloem. This bark piece is laid against the exposed xylem of the stock. Callus strands develop from terminal cells of broken phloem rays and adjacent young secondary phloem cells on the cut surface of the inner side of the bud piece. Correspondingly the cambium and the newly formed derivatives on the exposed surface of the stock also divide and form callus strands. Similarly from the side also callus strands develop.With the joining of all these callus strands a continuous callus bridge is formed. Short areas of cambial cells appear along the callus tissue. Secondary xylem and phloem are formed due to the activity of the newly formed cambium and the union is established between the stock and the scion. The vascular strands get connected to the original xylem and phloem.

There are three types of budding followed in mulberry: (i) Patch budding; (ii) T–budding; and (iii) Flute budding.

6.3.8 **Patch Budding:** A portion of the bark with an active bud is removed from the bark as scion (Figure 54). Correspondingly, a portion of the bark on the bud is removed from another stem to which bud grafting is to be made as stock. To this portion a bud of the scion is inserted and properly bandaged with a soft fibre and covered with grafting wax or grafting clay. Generally dried fibre of the petiole of plantain is used for bandage because of its softness, easy availability and moisture retaining capacity.

6.3.9 **T–budding:** A "T" shaped incision is made on the bark of the stock at the nodal region and a slit is formed by opening the cut ends. A bud cut out clean from the selected plant is inserted in this slit and properly bandaged.

6.3.10 **Flute budding:** The bark of the plant is cut to a length of 2½ to 3¾ cm round and removed as a sheath. Similarly, the bud of the scion with the same length of the bark is removed and inserted in the stock from where the bark is removed and bandaged properly.

The following precautions are to be observed for preparing bud grafts:

1. While removing the bud from the scion, no woody portion should stick to the bark.
2. Bandage should be done in such a way that water and air should not enter the budded area.
3. Sprouting of other buds on the stock should be inhibited.

6.4 **Layering:** Layering is another type of propagating mulberry. It is the development of roots on a stem while it is still attached to the parent plant. The rooted stem is then detached to become a new plant growing on its own roots. The layered stem is known as a layer.

The principle involved in the formation of roots during layering is due to interruption of the downward translocation of organic material, carbohydrates, auxins and other growth factors from the leaves or growing shoot tips. These substances accumulate near the point of treatment and induce rooting in that area even though it is still attached to the plant. This method is considered to be safe and cheap. At the same time not many plants are formed by this method.

Layering does not depend upon the length of time that a severed shoot can be maintained before rooting occurs. Due to this reason, layering is more successful in many mulberry varieties than those propagated through cuttings. This method is usually followed to obtain a large sized plant in a shorter time than it would have taken from a cutting.

There are different types of layering such as simple layering, air layering or gooting, trench layering, etc. A lower branch of a bush mulberry is bent down, a ring of bark is removed 2.5 to 5 cm in length around the stem, and this portion is pushed into the soft earth, made for the purpose, keeping the upper portion of the bark erect, the bent portion is covered with soil and a stone or brick is kept on it (Figure 55). When the roots have developed, usually within two to four months, the branch is cut off from the mother plant and is grown separately. This is simple layering.

6.4.1 **Air layering or gooting:** In this method, 1.2 cm circular bark is removed from the stem, where peat mass or well decomposed organic manure with a little quantity of root promoting hormones is placed at the region and tied securely with a polythelene cover. Water is regularly poured at the region. After two or three months, roots develop from the cut end. When the connection between the mother plant is severed it can develop into a new plant (Figure 56a).

6.4.2 **Trench layering:** This is mostly followed in Japan. It consists of growing a plant or a branch of a plant in a horizontal position in the base of a trench and filling in the soil and manure around the new shoots as they develop. Roots develop from the base of these new shoots under the same conditions as is done in simple layering. The shoot is covered along its entire length, but the tip is left exposed. New shoots which develop from the buds along with the stem grow upwards through the soil with roots at the base resulting in the formation of a number of layers from a single branch.

In addition to these, there are any number of methods followed in Japan such as Magedori, Chiba type of Magedori, Mukadedori, Shumakudori, Maritosi methods, etc. which are only slight deviations from the simple layering (Figure 56b).

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Chapter 7

MORICULTURE

7.1 **Climate:** Mulberry can be grown under various climatic conditions ranging from temperate to tropical. A perusal of the geographical position of the mulberry growing countries of the world indicates that all of them except Brazil are located north of the equator. Countries which are located in the belt of high latitude ranges of 28^{0}N to 55^{0}N are: (1) Japan, (2) China, (3) the U.S.S.R., (4) the Republic of Korea, (5) Yugoslavia, (6) France, (7) Spain, (8) Italy, (9) Greece, (10) Cyprus, (11) Turkey, (12) Hungary, (13) Syria, (14) Poland, (15) Bulgaria, (16) Iran, (17) Lebanon, (18) Afghanistan and (19) Romania. The countries which are located in the lower altitude ranges of 5^{0}N to 28^{0}N are: (1) India, (2) Sri Lanka, (3) Egypt, (4) Thailand, (5) the Republic of South Vietnam, (6) Indonesia and (7) Burma.

7.1.1 **Atmospheric temperature:** An atmospheric temperature, ranging from 24^{0}C to 28^{0}C is found to be optimum for good growth of mulberry. Growth and sprouting of buds cannot be obtained at temperatures below 13^{0}C and above 38^{0}C.

In temperate climates, mulberry starts sprouting in spring (April), when the temperature reaches 13^{0}C and continue to grow up to autumn (October). The plants remain dormant during November to March. Thus in temperate regions mulberry leaves are available for rearing purposes only during May to October. In the tropics, on the other hand, growth of mulberry is continuous throughout the year.

Rainfall: Mulberry can be grown in places with a rainfall range of about 600 mm to 2500 mm. Under low rainfall conditions, the growth is limited due to moisture shortage resulting in low yields. More than the total precipitation, rainfall distribution is important. On an average 50 mm once in ten days is considered ideal for mulberry.

7.1.2 **Atmospheric humidity:** Humidity range of 65 to 80 percent is considered ideal for its growth. Under rainfed conditions, due to higher moisture in soil and high atmospheric humidity, the quality of leaf produced during the rainy season is better than the leaf produced during other seasons.

7.1.3 **Sunshine:** Sunshine is also one of the factors controlling the growth of mulberry. In the temperate countries, mulberry grows with a sunshine range of 5.0 to 10.2 hours a day while in the tropics, it grows well with a sunshine range of 9.0 to 13.0 hours a day.

7.1.4 **Elevation:** In Japan, mulberry cultivation is practiced at altitudes from 22 m to 1735 m above MSL, while in the U.S.S.R., it is practiced 400 to 2000 m. Under tropical conditions in India, mulberry is cultivated at altitudes between 300 and 800 m above MSL. However, a range up to about 700 m above MSL is considered desirable for luxuriant growth of mulberry.

7.2 **Soils:** Soils of mulberry field have to maintain the mulberry plants for sustained maximum productivity of quality leaves. It has to supply (a) the essential major and minor plants nutrients, (b) oxygen for root respiration, (c) mechanical support or anchorage, and (d) as a storehouse for water. Since mulberry is a deep rooted, perennial, long–standing hardy and monoculture crop, the soil should be capable of supplying sufficient air, water and nutrients even in the deeper layers where the root system penetrates. The soil quality has an influence not only on the yield of mulberry leaves but also on their quality which in turn influences not only the growth of silkworms but also the quantity and quality of cocoons produced by them.

The soil should be deep, fertile, well drained, clayey loam to loam in texture, friable, porous and with good moisture holding capacity. Slightly acidic (6.2 to 6.8 pH) soils which are free from injurious salts are ideal for good growth of mulberry plant. Saline and alkaline soils are not preferred. For good growth of mulberry, the saline and alkali soils can be improved by the application of gypsum, sulphur or green manuring, while acid soils can be improved by the application of lime and green manure.

Mulberry is grown on a variety of soils in the major sericultural countries of the world. *In Japan* mulberry soils are divided into two major groups: (1) non–volcanic soil and (2) volcanic soils. Of the total area of 1,62,000 hectares under mulberry, 51.6 percent falls under non–volcanic soils and 48.3 percent under volcanic soils. Mulberry soils of Japan have been further classified into 36 groups — 15 groups belong to the non–volcanic soil major group and the remaining 21 groups to the volcanic soil major group.

The non–volcanic soils include mainly alluvial, colluvium and eroded, aeolian sand dune deposits, soil of consolidated and unconsolidated material, brown forest soil and red–yellow soils. They are rich in organic matter, low in phosphate fixation capacity and fairly high in water holding capacity. The soils on the slope are well drained while in the bottom of the valley they show impeded drainage. The soils are neutral to slighly acidic in reaction.

The major volcanic soils group comprises soils having a loose black "A" horizon with high humus and alumina content, high water holding capacity, strong phosphate fixation capacity and poor innate fertility. The volcanic soils are slightly to highly acidic. In order to neutralize the acidity in these soils periodic liming is resorted to.

The average mulberry leaf yield in non–volcanic soils is higher than the volcanic soils. Generally, the mulberry soils are low in fertility and hence intensive application of fettilizers is resorted to, to obtain maximum leaf yield.

In India mulberry is grown on a variety of soils. In West Bengal and Kashmir, it is grown in alluvial soils. These soils are generally grey, light brown to brown in colour, sandy loam to loam in texture, slighly alkaline to neutral in reaction and non–calcarious. They are generally deficient in nitrogen humus and occasionally in phosphorus.

In Karnataka, the mulberry soils are predominantly red loam, derived from granites and gneisses. The main characteristics of red sandy loam is shallow to medium in depth, well–drained, underlain with "murram" and gravelly substratum, colour bright red to pale brown, poor in water–holding capacity and in bases, sandy to sandy loam in texture, alkaline to neutral in reaction and the organic matter content is low. Most of the soils are deficient in available phosphorous and contain variable amounts of potash.

The next in importance comes lateritic red–loam. They are red to brown in colour, shallow to several cm in depth, poor in base and water–holding capacity, sometimes admixed with concretionary iron materials and are compact. Such soils require to be dug frequently and manured with organic manures to keep them sufficiently mellow for rooting. They are alkaline to neutral in reaction, deficient in organic matter,poor in available phosphorous and contain variable amounts of potash.

In some parts, mulberry is cultivated in black soils and these black soils are comparable to "chenozems" of temperate zone and differ from them in poor organic matter and humus contents. They are shallow to medium, clayey in texture with lime nodules, underlain with porous or rocky sub stratum, rich in bases, alkaline, low in organic content and high in water–holding capacity.

Mulberry grows best in a flat and fertile land. In places where there is a great pressure for land for agriculture and horticultural crops, mulberry can be grown even in marginal and slopey lands where other crops cannot be grown profitably. Mulberry plantation can be established in gentle as well as steep slopes. If the slope is below 15 percent, mulberry plantation can be established in rows along the contour whereas in steeper slopes (15 to 30 percent slope), terraces are built and mulberry planted.

7.3 Planting

7.3.1 **Location and Topography:** Mulberry plantation should desirably be established close to the rearing house for quick transport and immediate use of the leaves for feeding. The mulberry leaves after harvest lose considerable moisture and wither during transport, especially in summer, and hence, if the plantation is away from the rearing house, it will lead to wastage of leaves and economic loss to the farmer.

Mulberry plants grow best in a flat and fertile soil; however, it can be cultivated in slopey lands, provided proper soil and moisture conservation measures are adopted. It is necessary to improve the fertility level of such soils by supplying periodically compost farm yard manure and lime. Mulberry plants show very poor growth, in ill–drained soils. In such soils the plants have to be earthed up high and proper drainage should also be provided.

7.3.2 **Environmental factors:** Growth of mulberry and the quality of its leaves are often affected by various environmental factors; the neighbouring woods, buildings, factories, tobacco fields, orchards etc., greatly influence the quality of the leaves produced. In temperate climate, woods and buildings to the north of the plantation prompt sprouting of the buds, and those in the windward position serve as windbreaks, whereas when located on the southeast or southwest hinder the plantation from sunshine and consequent reduction in leaf growth. Sometimes smoke from the kilns of factories affects the quality of mulberry leaves. Liquid effluents from some factories are also harmful to the plants. Nicotine from the tobacco plants often contaminate the mulberry leaves and poison the silkworms. Hence mulberry plantations should be established at least about 100m away from tobacco fields in the leeward direction.

In recent years various kinds of agricultural chemicals are being used for control of pests and diseases of annual and perennial crops and most of these chemicals are harmful to the neighbouring mulberry plantations as the silkworms fed by such contaminated leaves are highly susceptible to the toxic effects. Hence care should be taken while spraying the pesticides to avoid contamination of mulberry plantations.

7.3.3 **Preparation of land:** After selection of land for mulberry cultivation, it is necessary to prepare the land in the proper manner. The field is to be levelled and the fertility level improved. When forest land is brought under cultivation after uprooting trees and the roots the soil is to be levelled. Levelling of the land depends upon its topography, such as flat terrain, slopey land and terrace type of fields. In doing so the level of the underground water table must also be taken into consideration, if the water level is high, proper drainage must be provided.

Mulberry plant is perennial and arboreous and its roots grow widely and deep in the soil. Hence a thorough preparation of the soil with a deep ploughing or digging is a prerequisite for mulberry cultivation, whether it is raised as a rainfed dry crop or as an irrigated crop. After cessation of monsoon rains, the land is prepared by digging, by means of a crow bar in case of small holdings and or deep mouldboard ploughing in case of large holdings, to a depth of 30 to 50 cm. The clods are allowed to weather. Then the clods are broken, weeds, stone and gravels are removed and the soil is brought to a fine tilth by repeated ploughing. Deep ploughing helps deep rooting, quick establishment and luxuriant plant growth.

7.3.4 **Planting season:** For proper establishment of mulberry plantations, early spring and late autumn seasons are best suited. Planting in winter and summer seasons are to be avoided. In Japan, usually the spring time, prior to the sprouting of buds, is the proper time for planting. However, depending upon the availability of labour, planting can be done in late autumn. When planting is made in spring, care is taken not to delay the planting, otherwise the sprouted buds fall off and the plants do not grow well.

In India planting season varies in different parts. In Karnataka, mulberry is planted during July–August, with the onset of South Western monsoon. Subsequent rains help proper establishment of the crop. In West Bengal, cuttings are planted during November (late autumn) after the cessation of North East monsoon rains. Planting during rainy season will result in rotting of the cuttings.

7.3.5 **Direction of planting:** In temperate regions the direction of the rows of planting is important. Depending upon the light intensity (sunshine hours) and wind direction mulberry seedlings are to be planted in rows either in north–south or east–west directions, making the rows parallel to the direction of wind. In tropics, where the sunlight is not a limiting factor, mulberry rows can be planted in any direction. In slopey lands the rows should be parallel to the contour lines.

7.3.6 **Planting distance:** The planting distance depends upon the agro–climatic conditions (sunshine, precipitation, temperature, etc.) soil fertility level, intensity of cultivation practices adopted including the training and harvesting methods and also the variety of mulberry planted.

When climatic conditions and agricultural inputs are not the limiting factors, maintenance of high plant density in an unit area results in increased leaf yield. To decide upon the optimum population density the variety of mulberry, training and harvesting methods to be adopted are to be determined first. Also the spacing along and between rows differs as to whether the plantation is raised as pure, mixed, companion or inter–crop. Regarding inter–plant spacing, considerations like number of branches, and branching habits of the variety, methods of training and fertilizer practices and moisture status in the soil should be kept in view. In general, mulberry varieties which have profuse branching habit must be planted with wider spacing than those having less branches. The inter–plant spacing within the row can be made narrower in mulberry plantations adopting medium cut training. In mulberry plantations raised under rainfed dry–farming conditions, where moisture is a limiting factor wider spacing is adopted.

Spacing varies in different sericultural countries of the world. In Japan, spacing adopted for the mulberry under different cut forms are as follows:

Table 4

Spacing for mulberry cultivation in Japan

	Inter row spacing	Inter plant spacing
Low cut form (low bush) (plant height below 0.6 m)	1.5 to 2.0 m	0.6 to 0.8 m
Medium cut form (medium bush) (plant height 0.6 to 1.2 m)	2.0 to 2.5 m	0.8 to 1.2 m
High cut form (small trees) (plant height over 1.5 m)	2.5 to 3.0 m	1.2 to 2.0 m

The mulberry is trained either as low cut (low bush) or medium cut (medium bush) and to a small extent as high cut form (small trees), particularly in cold places where heavy snowfalls occur. In the case of low bush, the plants are trained through pruning and kept as dwarf bushes with the main stem height at only 0.3 to 0.6 m above the ground level. The rows are about 1.5 to 2.0 m apart and within rows, the plants are 0.6 to 0.8 m apart. In the case of medium cut forms the stem height is maintained at about 0.6 m to 1.2 m. The rows are 2.0 to 2.5 m apart and within the row the plants are 0.8 to 1.2 m apart (Figure 57).

In the case of high cut bushes or small trees,the main stem is maintained at about 1.5 m height, the row spacing 2.5 m to 3.0 m and within the rows the plants are spaced 1.2 to 2.0 m apart. In the case of management with a tractor, the inter ridge (row) distance must necessarily be wider, according to the width of the machine. A wide interplanting distance will ease the farming operations but decrease the number of trees planted in a unit area and will result in less harvest. To increase leaf yield, the low-cut bush form with high plant population is advisable.

Of late, with greater emphasis on mechanisation of the practices involved in sericulture, the spacing and training of mulberry bushes are being evolved to suit the mechanical cultivation and harvesting operations. In general, on flat lands, a wider spacing is adopted while on a slopey land a more close spacing is followed in which case the plantation acts as a vegetative cover, reducing soil erosion.

In the Soviet Union mulberry is mostly grown as trees. However, bush type plantations are only of recent practice. The systems of mulberry cultivation in the U.S.S.R. can be broadly grouped under two headings viz (i) linear plantations and (ii) block plantations. Over 75–80 percent of the area under mulberry cultivation belongs to the linear type of plantations where mulberry is grown as small to medium sized trees, either along the roadsides or irrigation canals, or on the borders of the fields. The total number of trees under linear type plantation currently under cultivation is about 90 million. The spacing is about 3 m along the row.

Mulberry is raised as low to medium bushes or small trees in block plantations. The area under block plantation is about 1.2 million hectares. Since mulberry is raised as a pure crop, the spacing adopted under this system is comparatively closer. Where low bushes are raised the spacing along the row is 0.5 m and between the rows it is 3 to 5 m. For low stemmed trees, the spacing adopted is 4 m between the rows and 1 m along the row. In old plantations, however, a spacing of 4 m x 4 m is maintained.

Table 5

Spacing for mulberry cultivation in U.S.S.R.

	Spacing between rows	Spacing in between plants in the row
Block plantation	Inter-row spacing	Inter plant spacing
a) Low bushes	3.0 to 4.0 m	0.5 m
b) Low stemmed trees	4.0 m	1.0 m
c) Old plantations	4.0 m	4.0 m

In Uzbekistan, which is the major producer of cotton accounting for 70 percent of the total output of the Soviet Union, mulberry is raised in the cotton fields. It is either raised along the border as linear plantation or raised as block plantation with wider spacing, and cotton is raised in between the widely spaced mulberry plantations. In such cases the distance along the row is 0.5 m and between the rows it is 3.6, 6.3 or 9.0 m, to suit various methods of cotton cultivation.

In India mulberry is under a wider range of spacing, depending upon the variety, agro-climatic conditions, etc. In Jammu and Kashmir huge trees are utilized by lopping the branches for collecting the leaves. In most other parts, mulberry is grown with very close spacing as a pure crop. It is mostly raised as bush type in the states of Karnataka and West Bengal. In Karnataka, in rainfed areas

it is raised under pit systems with wider spacing (Figure 58). In some parts of Karnataka, such as Kolar Division, where intensive cultivation is practised with heavy manuring and irrigation. Closer spacing is adopted (Figure 58). In West Bengal, where the rainfall is heavy the "strip system" of close planting is practised.

Of the total area of about 1.05 lakh hectares of mulberry in India, Karnataka state accounts for 0.95 lakh hectares. Of this 0.20 lakh hectares are under assured irrigation, the rest under dry farming conditions in areas receiving an average rainfall of less than 600 mm. Since moisture is one of the limiting factors in mulberry production under rainfed conditions, wider spacing is adopted whereas close planting is followed under irrigated conditions. Different spacings in the planting in Karnataka are given in Table 6.

Table 6

Spacing for mulberry cultivation in India

	Spacing between rows	Spacing between plants
(i) Pit system (rainfed mulberry)	0.9 to 0.75 m	0.9 to 0.45 m
(ii) Row system (irrigated)	0.45 to 0.60 m (0.3 to 0.45 m)	0.45 to 0.60 m (0.15 m)

The general pattern under rainfed conditions is known as "pit" system of cultivation (Figure 59). The spacing between rows varies from 0.75 to 0.90 m and along the row it is 0.45 to 0.90 m. A spacing of 0.9 x 0.9 m and 0.75 x 0.75 m are adopted so that interculture operations in both the directions are practised with bullock drawn implements. In the case of 0.90 x 0.45 m spacing, intercultural operation is done by bullock drawn implements in one direction only.

Under irrigation, the row planting, known as "Kolar system" is followed. In this system ridges and furrows are made at a distance of 0.30 to 0.45 m. On either side of the ridges mulberry is planted at a distance of 0.10 m to 0.15 m between the plants along the row (Figure 60).

In West Bengal, where rainfall is heavy, a close planting called "strip system" is followed. In this method, spacing of 0.6 m between the strips is made. In each strip two to three rows are planted at a distance of 0.15 m. The distance between plants in each row is 0.15 m.

In Kashmir, huge trees are exploited for sericultural purposes. These trees are raised from grafts. Seeds of the local variety are sown in the nursery during summer and the seedlings are transplanted in the second nursery when about twelve to eighteen months old. Scions are obtained from the desired variety and root grafting is done on the seedlings. These grafted plants are allowed to remain in the nursery for two more years. When about five years old the grafts are transplanted to permanent places. From the seventh year onwards, leaves are harvested from the trees.

In addition to the old existing natural grown trees, new plantations are coming up as block plantations on canal bunds or as row plantations, etc.

7.3.7 **Planting material:** There are various methods of propagting mulberry plants. Generally, plant is raised either from the seed or through vegetative propagation from stem cuttings or layerings and grafts.

In most mulberry species the stem cuttings readily form roots. However, besides stem cuttings propagation through grafting and layering methods are also practised. Both grafting and layering need longer time for establishment. Hence propagation of mulberry through stem cuttings is preferred.

In Japan, mulberry is generally propagated either as grafts or through layering and seldom through seedlings. Planting material is obtained from root grafting and this accounts for 60 percent of the planting material. Therefore, establishment of mulberry plantations in Japan takes time. More recently hormonal treatment of the cuttings for better rooting is adopted. For this purpose both hard wood and soft wood cuttings are used. In case of hard wood cuttings the branches are cut during December and stored till spring. The cuttings are taken out during spring, dipped in hormone solution of 10 PPM naphthalene acetic acid (NAA) and planted in a nursery which is protected with a vinyl sheet cover. For soft wood cuttings, the branches with leaves are selected. The bottom end of the cuttings are dipped in 10 PPM of NAA solution and planted under vinyl or polyethylene film roof house. Within about 40 days of planting about 10 cm of root growth takes place, when the cuttings are ready for transplanting. Another method of obtaining planting material is obtained either from grafts, layers or cuttings, the saplings are lifted from the ground during late winter while lifting the saplings, care is taken not to injure the roots. The saplings with profuse roots are sorted out according to their thickness and selected for transplanting in the main field.

Before planting, the saplings are dipped in 1 percent Bordeaux mixture to protect the root system against fungal and bacterial infections. For protection against nematode infection, the saplings are soaked in hot water at 50^{0}C for one or two minutes. Soaking in lime sulphur or fumigation with hydrocyanic acid gas is recommended against attack of scale insects.

Both vegetative methods of propagation and propagation through seed are in vogue in the Soviet Union. Since propagation of mulberry by vegetative method is laborious and time–consuming, involving considerable labour, seed propagation is more commonly practised.

For multiplication through seedlings, the seeds are sown in April, in a well prepared nursery. The sprouted seedlings are transplanted in the second nursery during autumn at a spacing of 30 cm along the row and 60cm between the rows. The seedlings remain in the nursery for about two years, for hardening and crown forming. When the seedlings are sufficiently hardened with well developed roots and crown they are ready for planting in the main field.

In India, the planting material is obtained mostly from stem cuttings. Seedlings and graft methods are practised. Stem cuttings for planting are obtained from one year old bushes at the time of annual pruning. For preparing the cuttings only full grown thick main stem free from insect and disease attack is selected. The main stem is cut into pieces about 23 cm long with three to four sound buds in each cutting. It is well recognized that hard wood cuttings give the best results and hence while preparing the cuttings care should be taken to discard the tender portions of the stem.

The cuttings are planted directly in the main field itself. Sometimes when the field is not ready for planting, it becomes necessary to store the cuttings either in sand beds under shade or in wet gunny cloth, for about a week before planting. Both these methods of storage help callus formation and such cuttings give better performance. In some cases, the cuttings are planted in the nursery with a spacing of 30 x 15 cm and allowed to grow for about six months. Later,these rooted saplings are uprooted and planted in the main field.

7.3.8 **Removal of the planting material from the nursery:** Saplings are raised in the nursery well ahead of planting. Well grown one to two year old saplings are removed from the nursery, care being taken not to damage the roots or the main stem.

7.3.9 **Planting method:** After preparation of land, pits of a standard size of 40 cm width, 40 to 50 cm depth are made. Where inter plant distance is over 1.2 m, trenches of 45cm x 45 cm are opened in the planting row. Farm yard manure or compost is applied in the pits or trenches, at the rate of 15 tons per hectare, over which leaf mould up to a thickness of about 10 cm is added, chemical fertilizers at the rate of 80 kg N, 100 kg P_2O_5 and 50 kg K_2O) per hectare are also applied. After applying the fertilizers, the soil is filled to a depth of 5 to 10 cm and the saplings planted with the spacing as stated earlier. In order to plant the saplings at fixed intervals coir ropes with suitable marks are used for guidance.

The depth at which the saplings are to be planted is another important matter to be considered. If planted too deep, the saplings will not take roots well whereas when planted too shallow the spalings may not establish and may succumb to drought. Usually the stem portion of the sapling is buried 15 to 20 cm below the ground level the basal portion of the saplings is covered with soil and the area around the sapling levelled.

After planting, the saplings are cut to a uniform height. The height at which the saplings are cut varies according to the training system. In the low cut and medium cut forms, the saplings are cut 15 to 20 cm above the ground level. In high cut forms, which sets the length of the main stem at one metre or more, the saplings are cut to a height of about 10 cm from which a stout main stem is allowed to develop. During the following year the main stem is cut to a desired height. In this case, the completion of the plant form is delayed by one year. But the merit is that since a stout main stem is formed, the branches develop luxuriantly. When the main stem is one metre or more in height a support is provided to prevent the sapling lodging to the ground due to wind.

Under the "Kolar system" in India, after preparing the soil, ridges and furrows are opened at a distance of 0.45 m. Stem cuttings of 15 to 20 cm length are planted at a distance of 15 to 20 cm on either side of the ridges, with the help of a rope. The cuttings are planted at an angle of about 45^0, exposing one bud above the ground level for sprouting (Figure 60).

7.3.10 **Inter cultivation:** The main object of inter cultivation is to remove the weeds and loosen the soil so as to allow the rain water to soak deep into the soil and for better aeration and nitrification. Weeding is inevitable as the weeds compete for nutrients and water with the mulberry plants. It is desirable to plough at periodical intervals the inter row space to a depth of about 15 cm so as to eradicate the weeds (Figure 61).

Inter cultivation can be done either by means of bullock drawn or tractor drawn tillers and other implements. In the case of dry farming, in addition to the ploughing, ridging the mulberry rows is necessary so as to conserve moisture around the plant roots.

A more recent trend is to carry out minimum cultivation operations but to control the weeds through the application of chemical herbicides. The various herbicides used for controlling the weeds are given in Table 7 on the following page.

7.3.11 **Mulching:** Mulching is covering the soil in between the row space with some protective material. It helps in conserving moisture, keeps the soil loose and friable, protects the plants from winter injury, and keeps down the weeds. Pruned mulberry twigs are spread in between rows as mulches. Also paddy straw, leaf mould, autumn leaves, stubbles, etc. serve as natural mulches. Artificial mulches of black polyethylene sheet are also beneficial.

Table 7

Weedicides used in mulberry plantations

Name of herbicide	Dosage for 10 a.	Time of application	Remarks
1. Simazine (C.A.T.)	150–300 g (200 litres of water)	1st March–April 2nd May–June	1. Clean cultivation. 2. Spray before bud sprouting in spring and after summer pruning.
2. Karamax (D.C.M.U.)	200 ml	"	"
3. Paraquat (Grammoxone)	200–300 ml	"	"
4. Dalapon (D.C.P.A.)	0.5–1.0 kg	"	"

Chapter 8

IRRIGATION

Mulberry leaf production is often limited by the amount of available soil moisture and it can be substantially increased by supplemental irrigation. Since deficiencies of precipitation often occur in the major mulberry growing tracts of the world, it is necessary to provide supplemental irrigation to maintain optimum soil moisture conditions. Of all the inputs in mulberry cultivation, irrigation is known to bear the highest correlation with leaf productivity. It interacts remarkably with every other input. The water in plants, as in all other living systems, contributes as much as to the essential properties of life as do the more complex proteins, carbohydrates, etc. It is a well known fact that water is essential for most of the physiological reactions in plant tissues and in its absence life does not exist.

A large portion of the water taken up by the plant roots is lost through transpiration. For each unit of dry matter produced, the plant absorbs several hundred units of water. To produce one gram of dry matter about 280 to 400 ml of water is required. Over a period of 12 months about 50 to 60 acre inches or 125 to 150 cm of water has to be irrigated.

In order to make the most efficient use of water the methods and practices in irrigation must be based on the climatic factors and soil conditions. The following four approaches are followed for finding out the optimum irrigation schedules:

(a) physiological growth stages of the crop;

(b) soil moisture tension or depletion of available moisture;

(c) soil moisture tension–cum–physiological growth stages of the crop;

(d) cumulative evaporation from free water surface.

The evapo–transpiration loss in mulberry has been worked out as 4 to 5 mm per day. In addition to the total quantity, uniform distribution of rainfall during the growth phase of mulberry plant is essential. Where uniform rainfall at the rate of 100–150 mm per month is received, the crop needs no supplementary irrigation. But such ideal conditions do not exist in the major sericultural countries of the world, except perhaps in Japan. In the arid and semi–arid areas of most mulberry growing regions of Karnataka State in India, the rainfall is hardly 600 mm per annum and its distribution is also erratic and unpredictable. Thus, the mulberry crop raised under the monsoon rains suffers to a great extent due to the limited soil moisture conditions. In such mulberry growing regions, irrigation will have the profound influence on the leaf yield and quality of the leaf produced.

8.1 **Irrigation in relation to soil:** For efficient use of irrigation water, just enough water is to be applied to bring the moisture content of the soil in the root zone to its field capacity. If excess water is applied, it is lost from the root zone by downward percolation and this is a waste. The amount of moisture held in any soil is limited by its field capacity (upper limit) and wilting coefficient (lower limit). The moisture held by the soil between these two limits represents the available water. The amount of available water that can be stored in the root zone of the soil depends on its depth and soil texture and structure.

The available water held by soil is not uniformly utilized by the growing mulberry plant. At the field capacity level the plant draws more water from the soil and grows rapidly.The growth, however, progressively decreases as the soil moisture approaches the wilting point. In practice, the mulberry crop should never be allowed to extract more than 60–70 percent of the available water from soil, only then will there be well regulated plant growth and foliage production.

8.2 **Appearance of mulberry crop:** Mulberry plants with abundant supply of water are characterized by luxuriant growth, the foliage well developed and the leaves succulent and shiny. Whereas, mulberry plants of dry regions with limitation of soil moisture, tend to be stunted with reduced leaf size. A light green colour with succulency and glossy surface are generally indicative of adequate soil moisture and satisfactory plant growth. Stunted mulberry growth, with small dark green puckered and over and early matured leaves which became powdery and fragile are indicative of lack of soil moisture.

Mulberry crop growth should not lead to retardation for want of soil moisture. The practice of withholdingirrigation until the plants show wilting symptoms is not desirable since it would involve additional energy, water and nutrients for the plant to pick up normal growth. it is therefore essential to maintain ready moisture availability in the soil for satisfactory plant growth and leaf production.

8.3 **Frequency of irrigation:** Frequency of irrigation for the mulberry crop depends upon several factors such as growth phase of plant, soil type and other agro–climatic conditions. Frequency of irrigation can be determined by assessing the amount of moisture depleted from the soil by the consumptive use per day. In India the frequency may vary from around 15 days for clayey loam type soils to between 8 to 10 days for sandy soils. The most critical period of irrigation is during November to April. Thus 12 to 15 irrigations are given during November–April. In the Soviet Union, when mulberry is raised as a mixed crop, it receives five to six irrigations between April and October and when raised as block plantations up to eight irrigations in 12 months are considered necessary.

8.4 **Quantity of water irrigated:** The important considerations for the quantity of water to be irrigated is the root distribution pattern of plant, the climatic conditions and soil type. In order to provide effective irrigation, the following methods of soil moisture measurements are followed.

8.5 Measure of soil moisture

1. Gravimetric method of determination of soil moisture;
2. Using electronic properties of porous blocks;
3. Use of Tensiometers;
4. Neutron method of measuring soil moisture;

In Japan, mulberry is cultivated on undulating highlands, hilly and mountainous terrains where facilities for irrigation are limited and therefore the entire mulberry cultivation in Japan is under rainfed conditions. But fortunately unlike in Karnataka (India), where the bulk of mulberry cultivation is concentrated, the rainfall in Japan is abundant, ranging from 1000 mm to 2500 mm per year. The rainfall is also well distributed in Japan with a monthly rainfall ranging between 100–200mm particularly during March to October which coincides with the sericultural seasons. Thus mulberry crops do not suffer for want of soil moisture at any time and no supplemental irrigation is therefore found necessary.

In the sericultural areas of the Soviet Union, the rainfall is low, but mulberry crops are raised either in linear systems or block plantations, along with cotton and on the borders of agricultural crops and receive irrigation along with the companion and mixed crops.

Sufficient quantity of water has to be added to bring the moisture level to the field capacity and to cover the entire root zone. For mulberry it is necessary to bring the soil moisture level to field capacity up to three feet in depth. A quantity of about 50 to 75 mm per acre of water has to be applied uniformly to bring the desirable moisture level up to root zone. If excess water is applied, it will be lost from the root zone by downward percolation. If less water is applied it will not wet the root zone uniformly.

8.6 **Interval between irrigation:** When the mulberry plant is in the active growth phase, i.e. the sprouting and foliar developmental stages, the crop has to be irrigated frequently. In the tropics like India, plant growth takes place all the year round. However, moisture shortage occurs mostly during November–April. Monsoon rains are received between April and October during which period the crop does not require any supplementary irrigation. However, if there is unforseen drought during this period, the crop should be irrigated.

In the temperate regions like Japan, the active mulberry growth period is during March to October. During this period, the average monthly rainfall ranges from 100 to 200 mm. Thus the mulberry crops do not suffer for want of soil moisture and therefore no supplemental irrigation is required.

In the Soviet Union, the mulberry crop needs supplemental irrigation to keep a favourable soil moisture level between April and November and thus irrigation is practised.

8.7 **Quality of water:** In addition to the quantity of water, quality of irrigation is also equally important. Normally irrigation water for mulberry should contain less than 1000 PPM of total soluble salts.

8.8 **Methods of irrigation:** Of the different methods of irrigation adopted, the furrow, flat bed and basin methods are normally practised.

8.8.1 **Furrow method:** In the furrow method the field is laid out into a series of ridges and furrows (Figure 64). The basal part of the furrows is made wet by the flowing water and the ridge is moistened by the capillary movement of water. This method is more efficient from the points of view of economy in water use. Advantages of furrow irrigation are: (i) it is suitable for wide spaced as well as close spaced mulberry plantations; (ii) evaporation from the soil surface is relatively less; (iii) the ridges carrying the plant root system are freely aerable helping root development; and (iv) the furrow serves as a drainage channel during heavy rains and thus water stagnation is avoided.

8.8.2 **Flat bed method:** The field is divided into rectangular beds with bunds all around and channels on the sides (Figure 63). The bed size may vary from 3.5 x 2.0 m, to 4.0 x 6m. The advantages of this system are (i) it is suitable to most soil types; (ii) relatively economic in use of water; (iii) there is low wastage of water due to run off; (iv) the soil is not eroded; and (v) irrigation is relatively quicker than in other systems. However, more labour required for forming beds and wastage of space.

8.8.3 **Basin method:** The basin method is suitable mostly for tree plantations. In this system irrigation water from the supply source is lead into the basin around the trunk. The diameter of the basin may vary according to age and size of the tree from 1.0 to 1.5 (Figure 62).

8.8.4 **Overhead or sprinkler method:** This method of irrigation can be practised in undulating lands where low and high bushes are cultivated. The advantages are (i) most efficient in economizing water use; (ii) there is uniform distribution of water on the foliage; (iii) the percolation loss in porous and sandy soils is avoided; (iv) this is most suited for emergency irrigation; and (v) it can be followed with advantage on slopey and shallow lands. Even though the sprinkler method is highly efficient, the high cost of installation prohibits its adoption in the hands of economically poor Indian farmers (Figure 65).

8.9 **Influence on the leaf yield:** Yield of mulberry leaves is strongly influenced by both quantity and quality of irrigation water. The increase in leaf yield due to irrigation when compared with rainfed cultivation is given in Table 8.

Table 8

Effect of irrigation on the leaf yield of mulberry in India
(leaf yield in kg/hectare)

Treatment	1964–65	1965–66	1966–67	1967–68	Pooled
No irrigation	11 870	11 250	16 177	15 192	13 623
Irrigation	19 985	27 030	23 899	20 593	22 877

Added to this, the leaf production is increased three to four times when balanced fertilizers are applied at regular intervals in addition to irrigation.

8.10 **Influence on quality of leaf:** The nutritive value of the leaves is determined by chemical estimation and feed values as judged by the rearing performances, leaves obtained from irrigated mulberry possess more moisture and protein and are more nutritious than those from rainfed crops. Feeding the worms with leaves grown under supplemental irrigation generally improves the health of the worms, increases their larval weight, cocoon weight, shell weight and denier. Thus irrigation plays a pivotal role not only in higher yields of quality leaves but also the cocoon crops.

8.11 **Provision for drainage:** Provision of adequate drainage improves soil structure and its productivity. Under waterlogged conditions, the mulberry plants wilt under severe oxygen tension resulting in poor root respiration. The leaves become chlorotic and unsuited for feeding the silkworms. Also adequate drainage favours growth of soil microorganisms which play important roles in maintaining high fertility levels. It also helps in easy leaching out of excessive salts from the soil. Thus provision of proper drainage is as equally important as that of irrigation.

Chapter 9

MANURING

The importance of application of fertilizers and manures for both increased productivity and improved quality and quantity of mulberry leaves has been well recognised. It is fully realised that for any increase in leaf yield of mulberry per unit area of land, the native soil fertility alone cannot be relied upon and recourse has to be made to the application of fertilizers and manures. Of the three major elements, viz. nitrogen, phosphorous and pottasium, nitrogen is the most important and vital for increased production.

Table 9

Influence of the nutrients in fertilizers on the leaf yield of mulberry crops (yield in kg/ha)

	Japan		India	
	Yield	Index	Yield	Index
No fertilizers	7 630	41	16 452	52.7
No nitrogen	7 540	40	20 062	64.3
No P_2O_5	17 100	91	29 424	94.3
No K_2O	18 150	97	27 662	88.6
All the three nutrients	18 710	100	31 212	100.0

The data show the influence of the three essential nutrients on the leaf yield of mulberry. The yield of mulberry is influenced more by the amount of nitrogenous fertilizers than the other two. No nitrogenous fertilizer means no manuring in respect of mulberry crop. Leaf yield was reduced by about 10 percent and 6 percent when P_2O_5 was not applied, by 3 percent and 12 percent when K_2O was not applied, as per the studies conducted in Japan and India, respectively.

9.1 **Organic Manures:** The common organic manures used for mulberry are farmyard manure and compost. Growing of green manure crops in between mulberry rows and incorporating the same is also practised. Green manure crops like sannhemp, soyabeans and cowpeas are grown for the purpose. Neem cake and groundnut cake are also used to a limited extent. In Japan paddy straw, composted mulberry twigs and silkworm litter are also used as organic manures.

9.2 **Influence of Fertilizers on Mulberry growth:** Nitrogen is a constituent of protein and therefore a constituent of every living cell. It is the basic nutrient in the synthesis of proteins, amino acids, chlorophyll and alkaloids. In nitrogen deficient mulberry plant, the vegetative growth is stunted, the leaves dry up or shed prematurely. Nitrogen deficieny reduces the protein and the water content of the leaves, thereby reducing the nutritive value of the leaves. When nitrogen is supplied in optimum quantity and the plants put forth vigorous vegetative growth, the leaves enlarge in size, become deep dark green, indicating an increase in chlorophyll content. Thus nitrogen increases the vegetative growth, number, size and weight of leaves, and ultimately the yield. Also, the leaves become succulent improving their feed value to the silkworms.

Phosphorus is a constituent of cell nucleus, essential for cell division and development of meristematic tissues in the growing regions. The symptoms of phosphorus deficiency are not readily recognized by visual observation and less characteristic than those of nitrogen deficiency. In general deficiency of phosphorus causes stunted growth with small and very dark green leaves and the older leaves turn reddish purple.

Potassium influences the development of woody parts of the stem. It is essential both for photosynthesis and translocation of starch. When potassium is deficient, the older leaves become mottled and chlorotic, with necrotic symptoms along the margin. Though potassium deficiency is not apparently seen in most mulberry plants, potassium is essential from the point of view of sustained yield of quality leaves.

9.2.1 **Nitrogenous fertilizers:** Four major forms of nitrogenous substances used as manures and fertilizers must be recognized and they are: the water soluble proteins and other organics, the water insoluble organic non-protein substances, the nitrates, and the ammoniacals. The water insoluble organic sources of nitrogen do not readily leach from the soil and do not increase soil acidity. They are low in total availability and are expensive. The nitrates are readily available and are generally applied in the form of calcium and sodium nitrate. Following application, the nitrates are subject to leaching and are usually best applied in split doses. The ammoniacals are available to crops and are easily leached from the soil, but tend to increase soil acidity. However, this can be corrected with lime. When properly used, they are excellent forms of nitrogen for the plants. The non-protein organics such as urea are water soluble and are readily available. They are to some extent resistant to leaching, and only slightly increase soil acidity. Urea is an excellent form of nitrogenous fertilizer for mulberry. Its efficiency is high, especially when used in conjunction with small quantities of limestone. The use of non-protein organic calcium cynamide as an inorganic fertilizer is not common, except in Japan.

Nitrogen is usually applied in the form of ammonium sulphate (20 per cent), urea (45 percent), calcium ammonium nitrate (20.5 percent), ammonium sulphate nitrate (26 percent) and calcium cynamide (20 percent). The form in which it is applied depends upon the soil type availability and cost. However, acidic fertilizer may be preferred for alkaline soils, alkaline fertilizer for acid soils and neutral fertilizer for other types of soils. Fertilizers containing sodium may not be applied as it will increase sodium content leading to poor soil structure and drainage in the long run.

9.2.2 **Phosphatic fertilizers:** The two types of phosphatic fertilizers recognized are water soluble forms and citrate soluble forms. The citrate soluble forms are bone meal, rock phosphate and basic slag, and the water soluble forms are single and triple superphosphates. For mulberry the phospatic fertilizers, the water soluble single or triple superphosphate, are commonly used as it is neutral in reaction and the available phosphorous is as high as 90 percent.

9.2.3 **Potassic fertilizers:** The chief commercial potassic fertilizers are sulphate and chloride forms. For mulberry potassium sulphate and potassium chloride are generally used.

9.3 **Balanced use of fertilizers:** Instead of applying each nutrient separately, compound fertilizers containing NPK and also minor nutrients in small quantities are being recommended. Compound fertilizers are applied as basal doses and the straight fertilizers containing nitrogen are applied in split dose as top dressing in order to meet the full requirements of the plant. Of late, various complex fertilizers suited to different crops are available on the market.

Whenever the soils are deficient in micronutrients, these elements may be included in the compound fertilizers. In Japan, the NPK used for fertilizing the mulberry field is in the ratio of 2:1:1 or 5:2:3, while in the U.S.S.R. it is 2:1:1. In India, for irrigated mulberry crops the ratio of NPK is 2:5:1:1 and for rainfed crops 2:1:1.

9.4 **Influence of fertilizers on the quality of leaves:** Among the nutrients in fertilizers, nitrogen has the greatest influence on the quality of mulberry leaves. With the increased supply of nitrogen the percentage of crude protein in the leaves increases, while the percentage of sugars, phosphoric acid, potash and lime slightly decreases. The leaves become more succulent and their maturity is delayed. With increased application of phosphate, potash and lime, the nitrogen content of the leaves decreases. However, by balanced application of NPK the nutrition content in the mulberry leaves can be maintained at the desired level.

9.5 **Influence on the leaf yield:** Among the three major nutrients, nitrogen has a profound influence on the total yield of mulberry leaves. The effect of phosphorus and potash, though do not have such a pronounced effect on the yield as nitrogen, aid in increasing the efficient utilization of nitrogen and thereby improving the quality and quantity of leaves produced.

The interaction between fertilizers and moisture is very significant. The choice and application of fertilizers are related to the soil conditions and irrigation potential. The leaf yield by application of a balanced dose of fertilizer increases by 100 percent in rainfed conditions and by about 150 percent in irrigated conditions.

9.6 **Dosage of fertilizers and manures:** Quantity of manures and fertilizers depends upon the soil type, removal of plantation, rainfall distribution pattern, spacing, pruning and harvesting methods and also seasonal conditions. Thus standard dosages have been worked out in different sericultural countries and is presented below:

9.6.1 **Japan:** Compost or farm yard manure being slow acting, is applied during winter in Japan. Paddy straw, compost mulberry branches, silkworm litter are used as organic manures. Application of paddy straw is also common. Deep trenches are opened in between mulberry plants during winter months and paddy straw at the rate of 7.5 to 10 tons per hectare is applied, over which lime and nitrogen are added as correctives. The trenches are covered with soil and allowed to undergo decomposition in the soils.

The standard dosage of fertilizer is 300 kg N, 150 to 180 kg P_2O_5 and 180 to 200 kg of K_2O per hectare per year. This is applied in two equal split doses. The first application is made in spring, i.e. March–April, and the second in summer, in June, after pruning. The fertilizer is spread in between mulberry plant rows and incorporated into the soil by forking in or by working a rotary cultivator.

9.6.2 **U.S.S.R.:** The dosage of fertilizer depends upon the system of planting, age of the plants, their spacing and soil type.

When mulberry is grown along with cotton under a spacing of about 4 m, the following dose is applied. Also, the fertilizer dose is increased proportionately to obtain higher leaf yields.

Table 10

The recommended doses of fertilizers to meet increasing demands of plants for higher leaf yield

Yield of mulberry leaf (per ha)	Nitrogen	Phosphorus	Potash
4 tons	120 kgs	60 kgs	30 kgs
6 tons	180 kgs	90 kgs	45 kgs
8/10 tons	200 kgs	120 kgs	60 kgs

In the case of block plantations of bushes with a spacing of 3 x 0.5 m. the fertilizer schedule is 180 kg N + 90 kg P_2O_5 and 45 kg K_2O per hectare per annum.

Nitrogen is applied three times in equal doses, the first dose is applied when the bud starts sprouting in spring (March), the second dose 15 to 20 days after the harvest of leaf in spring (May) and finally 1½ months after the second application. Phosphorus is applied in one dose at the time of sprouting of buds, in early spring (March) along with nitrogen. Potassium at ¼ rate of nitrogen is applied to such soils which are deficient in potassium.

For the linear type of plantations, when the trees are planted on the borders of the field, the rate of fertilizer per tree is nitrogen 0.025 to 0.05 kg; phosphorus 0.012 to 0.025 kg; and potassium 0.06 to 0.012kg. For trees which are not grown on the borders of agricultural crops, the rate of application adopted per tree is nitrogen 0.300 to 0.400 kg and phosphorus 0.200 to 0.300 kg. In the case of trees, the fertilizer is applied only once in a year at the time of sprouting of buds.

9.6.3 **India:** In India, the recommended dosages of fertilizers vary from region to region and with the intensity of mulberry cultivation.

In Karnataka state, under rainfed conditions, organic manures such as farmyard manure or compost is applied at the rate of 5 to 10 tons per hectare, as basal dose every year, at the time of annual pruning. In addition to organic manures, fertilizers at the rate of 100 kg N, 50 kg P_2O_5 and 50 kg K_2O per annum is recommended. The fertilizers are to be applied in two equal split doses as follows: the first dose of 50 kg N, 50 kg P and 50 kg K applied deep in plough furrows on either side of the plant rows, two to three weeks after bottom pruning during June–July. These nutrients may be applied preferably in the form of complex fertilizers so as to supply the balanced NPK requirements. The second dose of fertilizers of 50 kg N is applied as any one form of commonly available straight nitrogenous fertilizers, after the completion of the first leaft harvest in September–October. The method of application is the same as mentioned above. It is very necessary that these fertilizers are applied before the cessation of monsoon rains so as to ensure that there is sufficient moisture in the soil for more effective utilization of the applied nutrients. Care should also be taken to see that these fertilizers do not deposit directly on the plant, especially on the foliage lest the foliage gets scorched.

Under irrigated conditions of intensive mulberry cultivation, 10 to 20 tons of farm yard manure or compost is applied annually as a basal dose. In addition, 250 kg N, 100 kg P_2O_5 and 100 kg K_2O per hectare is applied in five split doses in a year, corresponding to five leaf harvests. The schedule is as follows:

I crop: 50 kg N + 50 kg P_2O_5 + 50 kg K_2O (as complex fertilizer.)
II crop: 50 kg N as any one of the straight nitrogenous fertilizer.
III crop: 50 kg N + 50 kg P_2O_5 + 50 kg K_2O (as complex fertilizer.)
IV crop: 50 kg N as straight nitrogenous fertilizer.
V crop: 50 kg N as straight nitrogenous fertilizer.

In West Bengal, the manurial schedule is five to ten tons of farm yard maure or compost, fertilizer of 150 kg N, 60 kg P_2O_5 and 60 kg K_2O applied as three or four split doses.

In Kashmir, no manuring is followed for old trees. In new plantations, the schedule of application of fertilizers is similar to that of Japan.

9.7 **Time of application of fertilizers:** In temperate climates like in Japan and Russia, bulky organic manures which decompose and release nitrogen slowly, are applied during the winter, when the mulberry plants are in dormant stage. Water soluble nitrogenous fertilizers are applied in split doses during the growing season of spring and summer, so as to meet the extra nitrogen needed during maximum absorption period of the plant. First dose of nitrogen is applied just before the spring sprouting (March), the second dose after spring leaf harvest in June and the third application in July or early August. Phosphorus and potash are applied in single doses along with the first application of nitrogen.

In the tropics like in India, where mulberry is in active growth phase all around the year, with no prolonged dormant period (except in Kashmir), application of fertilizers depend upon monsoon rains. In the rainfed areas, where moisture is the limiting factor, fertilizers containing nitrogen are applied in two equal split doses, the first during June–July (i.e. during south–west monsoon rains) after pruning the crop, and the second application after the first leaf harvest in September–October (i.e. north–east monsoon). Phosphorus and potash are included along with nitrogen in the first application itself.

Under irrigated conditions, where moisture is assured with supplemented irrigation, fertilizers are applied in five split doses corresponding to the five leaf harvests. After every harvest, the crop is fertilized so that the crop is provided with nutrients in a regulated manner to obtain uniform leaf production.

9.8 **Method of application:** The two general methods of applying manures and fertilizers are broadcasting over the surface of the field and mixing it with the soil or localized placement. Organic manures are generally broadcast and the fertilizers are placed deep into the root zone. Deep placement is done either by means of a drill or the plough by furrow bottom placement. The advantages of deep placement of fertilizers are: (a) the nutrients will be kept moist in the root zone throughout the growing season; (b) band placement on the furrow bottom reduces fixation of phosphates by soil; (c) fertilizers are so placed that nutrients are readily available for complete utilization by the crop.

In the case of trees, side dressing of fertilizer is done around the plant and is called "spot application". The fertilizers are placed at a soil depth of 15 to 20 cm. Foliar spray is also done with urea at 1 percent concentration.

9.9. **Important of liming:** The main purposes of applying lime to soil are to neutralize soil acidity and to improve the physical properties of the soil. Lack of calcium causes rapid disintegration of terminal growing regions of shoots and roots. In Japan lime is applied to the form of ground limestone at the rate of 1000 kg/ha per year.

9.10 **Reclaiming alkaline soils:** Gypsum is applied in alkaline and saline soils as soil amelioration. The quantity of gypsum required per hectare of such soil is estimated on the pH level and the sodium salts present. Together with gympsum application, incorporation of heavy doses of composts or farm yard manure, with provision of adequate drainage are necessary to improve the productivity of the soil.

9.11 **Micronutrients:** In addition to the essential nutrients mentioned above, micronutrients like magnesium, boron, iron, manganese, copper, zinc and sulphur are also essential. Since these micronutrients are required in small quantities, the soil itself provides them to the plant.

Micronutrient deficiency symptoms in mulberry under field conditions are not quite clear. However, characteristic yellowing or reddening of leaves which appears first at the tips and spreads to areas between the leaf vein, especially in the older leaf, which eventually causes browning of leaves, may be due to the deficiency of magnesium. Iron deficiency is indicated by the appearance of chlorosis on the younger leaves and greening of midribs of the leaves. Manganese deficiency is indicated by the rugged outline and chlorotic condition of the leaves, and rotting in between the veins. The deficiency of boron often causes a breakdown of young growing tissues. In plants exhibiting boron deficiency, growth is slowed down and young tissues may actually disintegrate and cause the plant to crack, blacken or become abnormal in shape.Zinc deficiency usually causes chlorotic conditions of the leaves. It also causes scorchy yellow and brown leaf colouration, sometimes with darkened veins. Copper deficiency may cause wilting of the upper tender leaves and dying of leaf tips, often without pronounced bleaching or change of colour. Sulphur deficiency may cause chlorotic conditions in the leaves. The deficiency may also affect the protein synthesis in the leaves, as it is involved in the formation of amino acids essential for protein synthesis.

Japanese soils being acidic, are normally deficient in boron and magnesium and therefore three kg of borax and eight kg of magnesium oxide per hectare are recommended for application annually.

Chapter 10

PRUNING

10.1 Principles of pruning: Pruning is the methodical removal of certain branches of a mulberry plant with the object of giving the trees a convenient shape and size, to increase the leaf yield and to improve its feeding value. Pruning is essential to improve the yield in certain agricultural and horticultural plants.

In mulberry, pruning is practiced solely to improve the yield of foliage and to maintain the shape of the plant for early harvest of the leaf for silkworm rearing. Pruning of mulberry plants is also useful in adjusting the production period to synchonize with the leaf requirement for silkworm rearing, and also to extend the leaf production period in all the three seasons, viz. spring, summer and autumn. Pruning is one of the cardinal principles of mulberry leaf production technology. Trimming or shaping of plants into some definite cut forms is essential in mulberry cultivation for easy harvest and inter-cultivation. Pruning helps to divert the energies of the plant for optimum production of foliage. Due to the profuse branching habit, more branches than required for uniform distribution and optimum production may persist, thus creating a competition and struggle for existence. Many of the branches in adverse position may not get required nutrition and sunlight thus leading to wastage of energy. Systematic pruning helps in diversification of energies to the selected branches for higher yield.

Usually more branches grow on the top of any mulberry plant than can persist, therefore there is overcrowding. By pruning, the residual branches receive greater proportion of energy, make quicker growth and yield more and better leaves. Pruning is eventually a thinning process and is one of the cardinal practices in the growing of mulberry plants, similar to tilling and fertilizing.

Pruning is not a devitalizing process, but it is a means of invigorating for higher and timely yield of mulberry leaf. Only when pruning is carried out in excess or the cut wounds do not heal and hence lead to infections and diseases, it is harmful. By proper timing and method of pruning, it is possible to get two to three harvests in temperate regions and up to five to six harvests per year under tropical climates. In the temperate climates of Japan and the Soviet Union, the bud starts sprouting during spring, early April and continues to grow up to autumn (October) when leaf shedding takes place. During winter from December to end of February, the mulberry plants remain under dormant conditions. Thus mulberry plants are pruned in different ways according to climate, geographical conditions and forms of silkworm rearing. In Japan 70 per cent of the mulberry plantations are in the form of low cut training, while only 20 per cent is medium cut and 10 percent is high cut.

In Japan, silkworms are reared in two or three seasons of the year, i.e. in spring and autumn, in summer and autumn, or in spring and early and late autumn seasons. Consequently, pruning of mulberry trees is done to suit the rearing seasons. Summer pruning is practised for harvest in autumn and spring, while the spring pruning for the harvests in summer or autumn.

Cut forms: In order to get a guaranteed leaf harvest, every year, it is desirable to make a certain form or shape of a plant and maintain this plant form. This is achieved by adopting suitable pruning schedules. If the plant is kept in a certain form, routine pruning and management works become easy. The method by which the shape and form is maintained is called a *"cut form"*. The plant form is kept in order by annual pruning. In Japan the plant forms are classified by the height of the main stem, into three forms,viz. (i) low cut including semi-low cut. (ii) medium cut, and (iii) high cut. The length of the main stem is maintained below 50 cm in low cut form, one metre in medium cut and above one metre in high cut forms (Figure 66).

When the branches coming forth on the main stem are pruned every year, the part at which the cutting is repeatedly practised gets thick and shows a first shape in a few years. This training by which the branches are cut back every year to form a fist shape is called "fist form". This fist form facilitates pruning and many branches are put forth on the fist.

Another form in which two or three branches are raised from the main stem from which secondary branches are allowed to develop is called "non-fist form". The plant trained by the non-fist form occupies a wider space and also assures an increased harvest.

10.2 **Training: Low cut form and pruning:** At the time of planting, the seedlings are cut to a height of a 15 cm above the ground level. From this plant three or four branches arise. Prior to sprouting in the following year, stout branches are chosen and these are pruned so as to have five to ten cm length above the ground level. These branches are termed primary branches.

Table 11

Training schedule for low cut and semi-low cut forms practised in Japan

Cut forms	I year	II year	III year
1. Low cut (30 cm from base). 2. Semi-low cut (30–50 cm from the base).	Planting in April. Cut 15–20 cm from the base. In the late autumn season, cut 1/3 top shoot.	Primary pruning before budding (March) 10–15 cm. above the first cut (25–35 cm from the base). In late autumn 1/2 to 1/3 of shoot is cut and used for late autumn rearing.	Spring leaf harvest by shoot cut method followed by pruning in late May or early June and is known as summer pruning and is followed every year.

The thinner branches at the base are removed. On this primary branch, three secondary branches are retained. Therefore, during the second year each plant has about nine branches. In the third year, during the spring rearing season, all the branches are pruned at a length of three cm from the fist. During the spring rearing season of the fourth year, the branches are harvested, leaving a shorter length one to two cm from the fist. Thereafter, a similar harvesting process is repeated, and in a few years, a "fist shape" appearance eventually gives place to the growth of ten to fifteen cm of long stout branches. This form of training is designed for harvesting mulberry leaves for the spring rearing.

By adopting summer and spring pruning schedules it is possible to harvest mulberry leaves for spring, summer and early or late autumn rearings, from a plantation which was formerly used only for a spring harvest. After the leaf harvest for spring rearing the branches are pruned in May–June, when the plants grow fast, and this pruning is called "summer pruning" (Figure 67). From summer pruned plants, leaves are harvested for autumn and spring rearings. On the other hand, for harvesting of mulberry leaves for summer and autumn rearings, the branches are pruned in March, before spring sprouting of buds, and this is known as "spring pruning" (Figure 68).

10.2.1 **Types of pruning:** The medium cut forms include the fist form, non-fist form and various other forms of pruning.

(1) **Fist form**: The branches are cut at the base, maintaining a constant height. Fist style pruning promotes growth of latent buds, besides normal buds, thus making the plant grow into a small tree. By this method pest and disease control becomes easy (Figure 69).

(2) **Non-fist form:** Branches are cut leaving basal parts to some extent and in this style the trees become taller every year. This is better for the growth of mulberry trees, because by this pruning method normal buds grow with many branches. However, retaining old growths leads to retention of injurious pests and diseases which perpetuate, multiply and cause severe damage (Figure 69).

In any pruning system, it is necessary to maintain the mulberry plant in proper form. Even in grown up trees a suitable pruning method should be adopted to maintain a desired shape. Therefore trimming, viz., cutting unnecessary branches and dead woods, are not sufficient; it is necessary to carry out systematic pruning together with trimming.

In the tropical climates of India, where mulberry sprouts all the year round (except in Kashmir), pruning season depends upon the rainfall conditions, and the methods of leaf harvest. Under rainfed dry farming conditions, the plant is pruned once a year, during July–August, from 10 to 15 cm above the ground level and this is known as bottom pruning (Figure 71).

In some cases "middle pruning" is also practised. Middle pruning is a method of cutting the branches of bush mulberry 45–60 cm above the ground level, during December–January. Middle pruning stimulates sprouting of the lower buds in the bush mulberry, during winter season (Figure 70).

Under the "Kolar system" and "Strip system" of cultivation the whole shoot is cut to the ground level at each harvest (Figure 72). Thus the pruning and harvesting are combined together. In all, five harvests are made in a year and thus the plant receives five prunings. This is suitable only for tropical climates where mulberry sprouts all the year round, with no dormant period for bud sprouting. This type of severe pruning, however, needs heavy fertilization and irrigation.

In Kashmir, the pruning method is the same as that of Japan, since the climate of Kashmir is similar to that of Japan.

Low, medium and high cut forms are maintained in Japan, while in the Soviet Union only tree forms are maintained. In India, bush type is the general pattern. Bush form is maintained by pruning the plant to the ground level and allowing free tillering. Each bush gives about 5–6 stout branches. As discussed earlier, the form of the plant is maintained by adopting suitable pruning schedules.

Chapter 11

HARVESTING OF LEAVES

The method of harvest of mulberry leaves depends on the rearing practice in vogue in the locality or nation. The leaves are fed as a whole or as bits and in some cases the entire shoot or branch is used for feeding the worms. Furthermore, over the past several centuries the method of harvest must have become modified to suit the availability of labour and intensity of rearing practices. Thus in Europe, the U.S.S.R., Japan and parts of India, the entire shoot is cut and fed to the older worms so as to save labour cost whereas for feeding very young worms one has to necessarily harvest individual tender leaves, prepare them into bits and feed.

There are three methods of harvesting mulberry leaves viz., (i) leaf picking, (ii) branch cutting, and (iii) whole shoot harvest.

11.1 **Leaf picking:** In this method the leaves are picked individually from the plant. After the leaves are harvested from the main stem, the terminal bud is removed and the auxillary buds on the main stem allowed to develop (Figure 73). This results in a rapid development of the lateral shoots which would have otherwise remained dormant. Subsequently the leaves on the secondary branches are picked as a second crop.

When individual leaves are picked from the plant, the tender ones are fed to the young silkworms and as the worms advance in age, more mature leaves are picked and fed to them. In India the bushes are stripped six to seven times a year whereas in Japan and the U.S.S.R. only three pickings are possible. In these two countries because of high labour cost individual leaves are picked only to feed the young larvae during spring, summer and autumn months.

In India, the leaf picking starts about 10 weeks after bottom pruning and the subsequent pickings at an interval of about seven to eight weeks, thus obtaining six to seven harvests in a year, after which the bushes are pruned or cut down almost to the ground level. While picking the individual leaves from the plant, they are cut with or without petiole, the former being an easy and less labour consuming practice and the latter having no specific advantage over the former.

In the shoot plucking method the young shoots are harvested one by one. This is adopted for feeding larvae with chopped shoots or whole shoots and needs less labour. It is practised only for the spring rearings in Japan. But in case the shoot growth in summer and autumn months does not synchronize with that of the growth of larvae it is better to harvest suitably mature individual leaves for harvest.

11.2 **Branch cutting:** In this method the entire branch with leaves is cut and fed to the worms after the third moult. It is practised in Kashmir, West Bengal and parts of Karnataka in India and in Persia and Japan. In Kashmir it goes under the name of "Batchi" system and in Japan it is called "jossoiku". The advantages of this method are:

(1) It is easy in low and medium cut bush plantations.

(2) It saves labour in collection of leaf, distribution of feeds, bed changing and spacing.

(3) When cut branches are fed the leaf is utilized by the worms to the maximum.

(4) Since the branch rearing is usually practised on a shelf or on the floor rearing equipment trays, shelves, etc., are dispensed with.

(5) It helps in maintaining hygenic conditions in rearing the silkworms.

(6) The feed quality of the leaves are better as they are attached to the branches maintaining prolonged succulency.

11.3 **Whole shoot harvest:** This system is practised in Kolar region of Karnataka state and in Malda district of West Bengal in India. The branches are cut close to the ground level and the top is fed to the worms settled for fourth moult. Thus topping helps uniform maturity of the leaf left over on the plant. The effect of top clipping is that the energy which would otherwise go to the formation of new leaves is redirected to the leaves left behind on the plant, making them more uniformly mature. The shoots are generally harvested at an interval of 10–12 weeks, obtaining four to five harvests in a year. This method is suitable where the sprouting takes places all the year round.

In Japan and the U.S.S.R. the shoot harvest is done with mechanical harvesters. It is practised for the spring rearing. Leaves on young shoots of 20–25 days of sprouting are found to be suitable for chawki worms. As the worms grow older, the older leaves down the branches are harvested and fed.

Unlike mulberry leaves for the spring rearing, leaves during the summer and autumn periods the leaves of different maturity are seen on the mulberry plant.

There are individual preferences for different systems of harvesting, but as stated earlier availability of labour and its cost largely decides the method of harvest which in turn decides the method of feeding and rearing the worms.

11.4 **Time of harvest:** The quality of leaves is affected to some extent by the quickness in withering. Therefore the harvesting time in a day influences the length of time for which leaves can remain quality feed. Fresher the leaves better is their feed value. Therefore every effort is to be made to harvest quality leaves and keep them fresh for a longer period. Due to active photosynthesis and transpiration during the day time, the leaves harvested late in the afternoon contain comparatively less water and more carbohydrates and such leaves wither more readily than the leaves harvested in the early morning. It is, therefore, generally recommended to harvest the leaves in the morning hours.

11.5 **Preservation of leaves:** The fresh mulberry leaves are more palatable and nutritious to the silkworms. Under tropical conditions the branches, soon after harvest are covered with a wet gunny cloth. The individual leaves could also be harvested and collected in baskets covered with wet gunny cloth while being transported to the rearing house. Generally, the leaves are harvested twice a day and are preserved for successive feedings up to 24 hours as per the necessity. During this period the leaves should be preserved in moist, cool and clean places in order to preserve their succulency.

During the long period of storage, considerable nutritional changes take place in the leaves. The proteins are broken down to amino acids and the carbohydrates to simple sugars in the harvested leaves. These substances are utilized by the leaves for respiration during long preservation, in addition to the loss of water due to transpiration. Thus the leaves become poor in their nutritive value. The decomposition of molecules and consequent reduction in their nutritive value are in direct proportion to the changes in storage and atmospheric temperatures. Transpiration of water is inversely proportional to the relative humidity. Hence, care must be taken to keep the place where the leaves are preserved as cool and moist as possible. The ideal condition is below 20^0C atmospheric temperature and over 90 percent of relative humidity. Heaping up leads to fermentation and high storage temperature. To avoid this the leaves should be spread loosely in their layers and covered with wet gunny cloth or alkathene sheet. Table 12 gives the data on the differences between the three methods.

Table 12
Effect of storage on the moisture content of mulberry leaves and shoots

Method of storage	Total moisture % in 12 hr.	Total moisture % in 24 hr.	% of loss of moisture in 12 hr. duration	% of loss of moisture in 24 hr. duration	% of mositure present after 12 hr. storage	% of moisture present after 24 hr. storage
Leaf storage						
Check (no cover)	72.21	72.25	28.26	41.44	43.95	30.85
Alkathene cover	70.96	70.13	4.97	4.01	65.99	66.12
Wet gunny cloth	70.05	71.40	5.52+	3.55	64.53	74.95
Shoot storage						
Check	66.93	70.53	19.51	27.47	47.42	43.06
Alkathene	66.93	70.53	–	0.21	66.94	70.32
Wet gunny cloth	66.93	70.53	0.99	1.75+	65.94	72.28

If properly stored either in wet gunny cloth or alkathene cover, the leaves remain fresh for over 24 hours. In Japan in order to maintain the succulency of the leaves water is sprayedperiodicallyon the leaves and covered with perforated polythene sheets.

The leaves for young larvae must be kept in baskets lined with a clean wet cloth and also covered with a wet cloth. When the leaves are to be stored in bulk quantity for feeding to grown up larvae, they are preferably stored in wooden frames measuring about 1 1/1 m in length, 1.0 m in width and 0.8 m in depth and lined with wet gunny cloth (Figure 74). The leaves should be heaped loosely and they should be turned to provide free aeration and to prevent increase in temperature inside the heap.

Foliar constituents of mulberry: Succulent leaves which have attained full size are very suited for feeding silkworm larvae. The composition of leaves varies with variety, degree of maturity and the type of soil in which the plants are grown.

The protein content of leaves differs with the maturity of leaves. Generally young leaves are more acidic than older leaves. It has been found that accumulation of protein in larvae depends largely on the carbohydrates in the leaves. The specificity of mulberry leaf to silkworm larvae is due to attracting, biting and swallowing factors. The absence of any of these factors inhibits the feeding by larvae. Non–protein nitrogen accounts for nearly 22 percent of the total nitrogen in young leaves and the percent in mature leaves. Chemical composition of the leaves of different varieties in different stages are given in Table 13.

Table 13

Chemical composition of some important and exotic and indigenous varieties of mulberry:

(Mean of two seasons, Oct. 1969 and Jan. 1970 — Results on oven dry basis)

Sl. No.	Name	Type	Leaf moisture (%)	Total minerals (%)	Crude protein (%)	Reducing sugar (%)	Non-reducing sugar (%)	Total sugars (%)
1.	Local	Tender	71.22	10.38	23.17	4.42	9.78	14.20
		Medium	70.11	13.73	22.88	2.18	5.71	7.89
		Mature	69.06	15.59	22.53	1.68	4.72	6.40
2.	Kanva–2	Tender	73.37	12.17	23.44	2.25	6.13	8.38
		Medium	70.13	17.10	20.92	2.23	5.48	7.71
		Mature	69.82	18.73	18.27	2.06	3.96	6.02
3.	Saniish	Tender	63.99	13.81	20.16	2.82	5.13	7.95
		Medium	62.81	13.97	18.97	1.47	5.97	7.64
		Mature	62.72	16.09	17.84	2.30	6.53	8.84
4.	Kosen	Tender	73.24	10.47	21.31	3.81	7.47	11.28
		Medium	69.78	14.01	19.96	2.06	4.29	6.35
		Mature	61.98	19.70	17.71	1.74	5.14	6.89
5.	Tonieso	Tender	67.95	11.91	22.60	2.67	9.68	12.35
		Medium	64.37	17.53	17.25	2.39	6.40	8.80
		Mature	61.40	20.41	16.94	2.21	5.78	7.99

Chapter 12

DISEASES AND INSECT PESTS

12.1 **Diseases:** There are different kinds of diseases of mulberry which are caused by fungi, bacteria, viruses and also mineral deficiencies or physiological disorders. Of these, ten or twelve diseases cause much damage to mulberry plants. They are widespread in all the mulberry growing countries of the world. Their incidence, however, varies with seasonal factors, mulberry varieties and cultivation practices. The diseases affect different parts of the plant. The mulberry being a perennial crop the pathogens seem to readily perpetuate and quickly spread to cover extensive areas. Certain alternate and collateral hosts (mainly weeds) play some role in perpetuation of some of the pathogens. The economy of sericulture is severely affected since both the quantity and quality of the leaf produced are affected by the diseases.

12.1.1 **White root rot:** White root rot is caused by the pathogen *Rosellinia necatrix,* Berlesse, belonging to the class Ascomycetes. The diseased mulberry plants become weak, the leaf buds grow feebly, the leaves wither off and soon the plant dies. The stump region of the affected plants are covered with whitish gray mycelial mat (Figure 75), extending deep into cortex, cambium and pith tissues. The mycelia are septate. The fungus reproduce by the formation of chlamydospores (which are thick–walled resting spores), and sclerotia and rarely through conidia. Under favourable circumstances, it reproduces sexually. Asci are enclosed in the perithecium and in each ascus there will be eight ascospores. The hyphae emerging from the various fruiting bodies attack the smaller roots of the healthy plants, and spread to the main root system causing white root rot. The sclerotia can remain for a long time in the soil and perpetuate the disease. The white root rot fungus can infect many other host plants and hence there is easy perpetuation and quick spread of the pathogen.

12.1.2 **Violet root rot:** This is caused by the fungus *Helicobasidium mompa,* Tanaka., belonging to the class Basidiomycetes. The chief symptoms of the disease are, sudden withering of leaves and collapse of plants during rainy season. The epidermal tissues of the larger and smaller roots are covered by thick whitish–violet coloured mycelial mat (Figure 76). Not only the epidermal tissues rot but as the disease advances the rotting spreads to the xylem tissues also. Microscopic examination of the infected portions reveal a number of purplish septate hyphae terminating with fructification bodies, called basidia. Each basidium bears four basidiospores at the top. These basidiospores readily germinate inwet soils,or in the rain drops. The germinating spore becomes the nutritive hypha which enters the new roots and infect them. Under adverse conditions, the mycelia form the sclerotia or the hardened masses of hyphae. They remain for a long time on the dead root tissues or in the soils and later germinate during favourable seasons to produce new hyphae which infect the plant roots. This pathogen can also live in many other host plants and perpetuate indefinitely.

Control of root rot diseases: As soon as the symptoms appear, the diseased plants should be uprooted. A metre deep pit is dug around the diseased plants and the soil excavated should be piled up in an isolated place to prevent the spread of the diseases. The stump, root pieces barks and other plant parts should be collected and burnt. The soil around is then ploughed, levelled and disinfected. Holes (a metre deep) are made in the ploughed field into which about 450 grams of chloropicrin is dropped per square metre and the holes are then covered with soil and the field is sprinkled with water. The chloropycrin fumigates the soil. The disinfected field may be left as such for a few days before replanting. This treatment helps in controlling the soil borne pathogens.

The soil in the infected region can also be disinfected by mixing Calcium cynamide in a ratio of about 2400 g per m^2 of land. This treatment is effective in shallow soil plantations. Before replanting, the disinfected soil may be tested for the presence of the fungal spores and sclerotia to make sure of the efficiency of chemical disinfection. The new saplings before planting may be treated by washing them in 20 percent lime water or one percent copper sulphate solution for an hour followed by thorough washing with water as a preventive measure against any infection.

12.1.3 **Mulberry trunk rot:** This disease is caused by *Polyporus hispidus* (Bull) Fr. belongs to the class Basidiomycetes. The affected trees show symptoms such as drying up of branches and rotting of branches and trunk, terminating in the death of the tree. The careless and incidental wounding and the cut ends due to pruning form the entrance for the pathogen into the host plant. In order to protect the plant against such infections, the cut wounds should be covered with a suitable fungicidal paste. Also, in the infected plant, the diseased stem should be cut at the base and the cut ends coated with fungicidal paste.

Other common diseases of the stem are gummosis and canker. Apart from these, several fruticose and foliose lichens and a few algea grow on the mulberry trunks, but they do not cause much damage to the host plant.

12.1.4 **Leaf spot diseases:** Several leaf spot diseases are reported on mulberry. They are caused by *Cercospora moricola* Cooke, *Septogloeum mori* Briosi and Cav, and species of *Alternaria* and *Helminthosporium*. These pathogens belong to the class fungi imperfectii. The diseased leaves have a number of circular or irregular brownish black spots of varying sizes (Figure 77). Usually the incidence is more during rainy seasons. The infected leaves are not suitable for feeding the silkworms. Considerable variations in the disease incidence amongst different varieties of mulberry is observed. The fungi reproduce by the formation of conidia from the conidiophores, which spread rapidly to other plants and affect the leaves. In the case of Septogloeum and Cercospora the conidia are formed in bundles, emerging out of the epidermis of the leaf and are scattered by the wind.

Prevention and control: Spraying suitable fungicides (eg. Difolatan 0.2 percent) on the young leaves (soon after picking or pruning, i.e. before the onset of the incidence) prevents the infection. The sprayed leaves should be fed to silkworms only after a certain period of time to avoid toxicity. Proper cultural practices like weeding out the alternate hosts, removing the affected leaves, and fungicidal sprays can effectively control the incidence of leaf spots.

12.1.5 **Powdery Mildew:** This is caused by the pathogen *Phyllactinia corylea* (Pers) Karst, belonging to the class Ascomycetes. The disease is common in all temperate regions. It is more common during winter and following rainy seasons in the tropical regions. Usually in the hilly areas, it is commonly found by the end of the monsoon seasons. The lesions first appear as whitish patches on the lower surface of the leaves. Gradually, they turn yellow–brown to black coloured patches and quickly cover the entire leaf surface (Figure 78). Finally the leaf becomes dry, less nutritive and falls off. The diseased leaves are unsuitable for feeding the silkworms. The whitish powdery material seen on the leaves consists of the fungal hyphae and conidia. The hyphae spread on the leaf surface, sticking fast to the epidermis and getting nutrition from the host through haustoria sent into the mesophyll tissues. The vegetative hyphae produce a large number of long hyaline erect conidiophores which cut off oval shaped conidia at their tips. These conidia spread on to the healthy leaves through wind and affect other plants: Some of the hyphal ends produce the cleistothecia — flat sphere–shaped, papillate fruiting bodies in which there will be many asci. Each ascus bears 2–4 or 8 ascospores. The ascospores, after maturation are liberated, and they germinate on the healthy leaves.

Prevention and control: Dusting fine sulphur or spraying dithane, sulphur suspension or lime sulphur mixture on the back of the leaves may be effective. But care should be taken not to feed these leaves to silkworms. Growing mildew resistant varieties of mulberry. Picking and destroying the affected leaves.

12.1.6 **Mulberry Rust:** It is caused by the pathogen *Aecidium mori* (Barci) Syd. et Butler, belonging to the class *Basidiomycetes*. The pathogen infects the leaves and green woody portions of the plant. The affected green portions swell up and get deformed, with dark brown lesions and finally break down. The affected leaves have whitish brown pustules on both the sides and are deformed and not nutritive. Therefore, they are not to be fed to the silkworms. The aecidium develops quickly and the aecidiospores cannot hybernate for a long time. The spores enter the healthy host leaves and germinate when conditions are favourable.

Prevention and control: Spraying sulphur suspension or lime sulphur mixture in appropriate concentration on the plants is effective in controlling the disease, but the sprayed leaves should be fed to the worms only after a safe period i.e. when no residual toxicity of the fungicide is there. The infected leaves and stem portions, and the suspected diseased plants should be removed and burnt.

Apart from these diseases, in the temperate regions like Japan, the mulberry plants are affected by blight diseases.

12.1.7 **Dogare blight:** Dogare blight is caused by *Diaporthe nomurai,* Hara. This is a common blight in Japan. The symptoms are, lack of bud formation in the branches and sudden withering of shoots. The bark will have brown eruptions, where the pycnidiospores are found in groups inside the pycnidia. After liberation from the pycnidium the spores are scattered on to the healthy leaves and stems and cause the disease. The spores enter the lenticels of the healthy plants and germinate and penetrate deep into the stem tissues and live in saprophylic conditions. The diseased cuttings when planted after winter perpetuate the disease.

Prevention: Selection of resistant mulberry, high cut pruning, and cutting and burning of the infected plants are recommended to prevent the disease. Lime-nitrogen solution, lime sulphur mixtures and Epsom solutions are effective when used before the incidence of the disease as preventive measures.

12.1.8 **Twig blight:** This is also called "Megare" disease and is caused by the pathogen *Gibberelle moricola* (De Not) Sacc. It is common in Japan and other temperate regions. The twigs are affected by this pathogen. Around the diseased twig portions, reddish brown lesions appear. These lesions coalesce and expand and cut off the sap movement in the twigs. This causes sudden withering of buds above the infected area. The mycelial ends coming out of the lesions form conidiosphores, which produce conidia at the top. The perithecium is spherical in shape and contains club shaped asci. In each ascus eight ascospores are formed. The conidia and spores germinate in any injured part of the twigs and cause the disease in the healthy plants.

Prevention and control: Removal of infected twigs and spraying the plants with suitable fungicides recommended for checking the Dogare blight disease are effective in preventing megare blight also.

12.1.9 **Shownia disease:** The leaves develop rusty brown patches, showing deficiency of potash, proteins and sugar contents. The exact cause of the disease is not established. This disease is common in some parts of West Bengal in India. The diseased leaves are poisonous to the silkworms and may cause flacherie. Heavy rains may favour the onset of this disease. Potash manuring may prevent the incidence.

12.1.10 **Bacterial diseases:** Three different pathogenic bacteria cause diseases in mulberry:

(a) Bacterium moricolum, Yendo et Higuchi: This short rod shaped,nonmotile, gram positive bacterium erodes the base of the twigs and forms a whitish colony around. It is noticed usually at the ground level in the affected twigs. The lesion encircles the twig and the tissues rot. The phloem tissue decays and the xylem also get affected. In the infected plants the leaves wither off and the twigs become weak and break off.

(b) Bacterium mori Boyer et Lambert, and

(c) Bacterium cubonianus, Macchiatti are mostly similar in nature affecting the mulberry following the rainy season. B. mori is rounded in shape, motile, gram negative and forms whitish colony. B. cubonianus

is rounded in shape, motile, gram positive and forms a yellowish colony.The leaves and the stems are affected and the growth of the plant is arrested. At times the axillary bud sprouts early, below the infected area forming small and weak secondary branches. The green lesions on the lamina are sporadic, circular in shape, and become brown coloured. The affected portions become brown, rotten and distorted and the whole leaf gets deformed. Irregularly shaped lesions are also formed on the petiole and veins. The bacteria hibernate in the branches and increase in number with the onset of the monsoon. They also survive in the soils for some months. They may enter the plants through wounds and perpetuate during the off season in the infected plants or in the alternate hosts or in the soil.

Prevention and control: The following measures are recommended for controlling the diseases:

(1) Too much of dense planting with less of cultural practices cause these diseases, so these should be avoided.

(2) Care should be taken to give high cut training to the plants.

(3) Infected soils should be treated with calcium cynamide (lime nitrogen) applied at 50 kg/ 10m^2 area.

(4) Tilling and levelling the soil at the stump area are advisable,and

(5) Removal and burning of infected plants are essential.

12.1.11 **Diseases caused by viruses:** Mulberry plants are affected by some viruses and mycoplasma of which two are common.

(a) **Dwarf disease:** This disease is caused by mycoplasma. The disease is transmitted by insect vectors such as leaf hoppers, Hishimon–yokobai (Hishimonus sellatus uhler) and Hishimon–modoki (Hishimonoides). Due to this disease, the leaves become yellow, and disorderly arranged. The growth of the branches is retarded and they become fragile with shortened internodes. Many laterals will shoot up from the branches. The roots have poor vasculature and the cellular lignification becomes insufficient. Finally the pith hardens and the plant dies.

(b) **Mosaic disease:** This disease causes wrinkling of the ventral surface of the leaves together with chlorotic conditions. The leaves become distorted and twined. The mesophylls disappear at the veinlets and yellow spots appear. The tips of the branches are shortened and rosettes or dwarfed branches are formed. With the advancing of disease, the plant slowly dies. The virus is transmitted by grafting or by unknown agents including insect vectors.

Prevention and control: The following steps are recommended for controlling the virus diseases:

(1) Growing resistant varieties.

(2) Selection of saplings and cuttings from disease free plants and growing them in disease free plots.

(3) Proper cultural practices.

(4) Eradication of insect vectors by spraying suitable insecticides.

12.1.12 **Deficiency diseases of mulberry:** Apart from diseases caused by various pathogenic agents, mulberry plants show symptoms of many deficiencies in minerals. The following are some of the common deficiency diseases noticed in mulberry.

(a) **Nitrogen deficiency:** This causes a slow, weak growth of plant with less branching and chlorosis of leaves. The young green leaves show mottling and chloritic spots (Figure 79). The stem is slender and light yellowish green and the root system also becomes stunted. The nitrogen deficient leaves do not support a good growth of silkworms.

Application of requisite quantities of nitrogen fertilizers like urea, ammonium nitrate, calcium nitrate, etc. cures the deficiency.

(b) **Potassium deficiency:** The deficient plants show marginal scorching (drying) of leaves and later the leaves become course, non–juicy and necrotic (Figure 80). The stem and roots become slender. The plant may not have good growth even if other elements are present in the soils. Proper fertilization of the soil with potash fertilizers is useful in curing this deficiency.

(c) **Phosphorus deficiency:** This becomes apparent in the plants as intra–veinal chlorosis of older leaves. The chlorosis spreads throughout the leaf and this is followed by marginal necrosis and defoliation (Figure 81). The stem will be slender without fresh growth and the root system becomes stunted.

Fertilizing the soil with a balanced NPK fertilizer helps overcome this deficiency.

(d) **Magnesium deficiency:** Magnesium deficiency causes chlorosis of older leaves and necrotic spots on the leaves. The leaf tips and margin become dried and scorched. Application of magnesium sulphate or magnesium oxide is requisite quantities can prevent the deficiency in the plants.

(e) **Calcium deficiency:** Calcium deficiency causes deformation of young leaves, with necrosis along the veins and makes the leaves pale. The stems become woody and short with yellowing tips and the roots become stubby and dry. Liming the fields with requisite amount of lime, prevents this deficiency.

(f) **Sulphur deficiency:** There will be slight chlorosis of the leaves with general lack of new growth. The stem becomes slender. Application of sulphur containing fertilizers helps in alleviating the disease symptoms in plants.

In addition, many other trace elements may also be necessary for the healthy growth of mulberry plants. These minerals support good vegetative growth of quality and quantity of leaves and in building resistance to diseases and pests. A close and methodical observation, timely supply of requisite mineral elements and proper cultural practices prevent the occurrence of deficiency diseases and boost the quality and quantity of leaf produced by the crop.

12.2 **Insect Pests:** Mulberry, like most of the economic plantations and field crops is often attacked by various insect pests. Frequent leaf picking and pruning of the shoots, even though they restrict the attack of pests, many insects find enough time and place on mulberry for their feeding and breeding habits. The damage caused by the pests is quick and extensive. Lepidopteran insects, thrips, and mites cause considerable damage to the mulberry. The attack by these pests is sporadic and sometimes seasonal. The damage caused by them varies, some eat the entire leaves, others feed on buds and tender leaves, some others suck the sap of the leaves and play important roles as the vectors of virus, thereby affecting the growth and the leaves become unfit for feeding the silkworms. Stem borers construct tunnels into the stems of mulberry to destroy the host plant. The pests of mulberry can be broadly divided into those of Lepidoptera, Coleoptera, Thysanoptera, Homoptera and others.

Lepidopteran pests

12.2.1 ***Diacrisia obliqua*** WALKER: Belongs to the family Arctidae of Lepidoptera commonly known as "Bihar hairy caterpillar". It is a polyphagous pest and is responsible for the highest damage to mulberry plants. It feeds on castor and is a pest on jute. The caterpillars are voracious leaf eaters and they devour the leaf very fast causing extensive damage and hardship during silkworm rearing. In

Karnataka (India) their incidence is frequent from November to January. The life cycle of the insect is completed in 48 days, with a larval duration of 30 days (Figure 82).

Life cycle and habit: Egg: 1000–1200 eggs green in colour with a metallic shining colour are laid by the female moth in small batches on the lower surface of the leaves. The incubation period is five to seven days.

Larva: The hatched larvae are dull white in colour with prominent black head and the body covered with small hairs. They measure 0.2 cm in length. They are gregarious in habit and cluster together on a single leaf. Morphologically the second stage larva is similar to the first stage larva except for its size, while the third stage larva is yellowish brown in colour. Larvae devour the chlorophyll region during their early stage and leave behind the veins which look like a dried leaf. The larvae after the third stage start dispersing to different branches. At the fourth stage the head is black. The anterior and posterior portions of the body are black in colour and the middle portion is yellowish brown in colour. A dorsomedian streak is visible extending from head to anal segment. There are 12 tubercles present on each segment provided with a number of hairs. Three types of hairs are found viz., white, yellowish brown and black. There are six larval moults before they attain full size. Fully grown larva measure 4.5 to 5 cm. The final stage lasts five to seven days.

Pupa: They pupate in loose soils. The pupa lies inside a thin silkin cocoon formed by the interwoven shed hairs of the larvae. It measures about 2 cm and is dark brown in colour. The pupation lasts for 12–14 days.

Imago: The moths are light brown in colour. The abdomen is brick red with rows of black dots on lateral and mid dorsal sides. The wings have scattered black spots. The female moth with wing expanse of 4.5 cm measures 1.75 cm in length. They are nocturnal in habit.

Control measures: (i) Collection of egg masses in a mechanical way to reduce the number of successive generations. Early stage larvae can be identified by their gregarious habits and the dried leaf on which they feed can be collected and destroyed. (ii) Deep ploughing and flood irrigation is useful in killing the pupae which pupate in soil. (iii) Biological control: In nature, a Hymenopteran parasite, Apanteles obliqua, is found to parasite the larvae by laying the eggs on the body. The prasites puncture the host larva to come out for pupation, thus killing the host. (iv) Chemical control: 0.2 percent D.D.V.P. can be sprayed to kill the larvae and the sprayed leaves can be used for silkworm rearing after three days.

12.2.2 **Eupterote mollifera,** W: Is a brownish hairy caterpillar belonging to the family Eupterotidae, commonly found in tropical countries.

Life history, habit: Eggs are laid in a closely attached mass around the tender twigs or on the petioles of the leaves. The eggs are more or less round in shape, slightly flattened at the top with a small depression, sulphur yellow in colour when freshly laid, and later changing to brownish yellow with a pale halo around the depression (Figure 83). Incubation period lasts nine to thirteen days after laying.

Larva: Larval duration is about 68 days and it completes generally four moults and occasionally also six moults. The first stage larva varies from 4.5 to 5.00 mm, in length, is brownish yellow in colour with thirteen pairs of hairy tuffs, one pair on each segment. A pale white streak runs along the mid-dorsal surface from head capsule to the 1st abdominal segment. The legs and pro-legs are darker in colour, prolegs are armed with 28–32 crockets. The first moult takes place about seven to thirteen days after hatching. The second stage larva is 6–8 mm in length, head capsule is tinged with orange colour, ocellii are prominent, the legs and prolegs are dark in colour and the prolegs are armed with crockets. The third stage larva is brownish in colour with tufts of hair and measures 16–18 mm. The third moult of the larva

occurs 12 18 days after the second one. At the IV stage it is brownish grey with numerous dark spots scattered all over the body. A number of parallel streaks are present on the body giving a characteristic pattern. The general pattern of the prominent hairy tufts is a cushion-life pad with a light coloured halo around it. Each of the black spots present on the body seem to be armed with a pectinate seta like hair. The fourth stage lasts for eight to twelve days. The size of the fifth stage larva is 48–49 mm and the fifth and sixth stage larvae appear black in colour. The larva of sixth stage is 50–55 mm and it lasts for twelve or eighteen days.

Pupa: Pupation takes place in a soft thin cocoon made up of silk secreted along with the hairs of the caterpillar under the leaves. The average size of female pupa is 18–20 mm and is dark brown in colour. The pupal stage lasts for about 35 to 60 days.

Imago: Female moths are larger and stouter in size and are dark brown in colour, the antennae are pectinate and a dark band runs parallel to the apical margin on both the wings. The wings are clothed thickly with long scales. It is about 55–58 mm along the wing span. The male moths are light yellow in colour and are smaller in size. The antennae are well developed and of plumose type. They measure about 48–52 mm in length. The abdomen is very slender and tapering towards the last segment, which is cleft into two.

Control measures: Some dipteran flies are reported to parasite the larvae, the maggots complete their life cycle in eight days and emerge out puncturing the host body.

12.2.3 **Amata passalis,** FB: This is a minor pest of mulberry occurring throughout the year in Karnataka (India) belonging to the family Amatidae.

Life history and habit: Eggs: The eggs are laid by female moth in three masses on the ventral surface of the leaves. They are small slightly yellow in colour and round in shape measuring 0.67 to 0.69 mm and about 500 in number. Incubation period lasts for six to seven days.

Larva: The larval stage lasts for about 32 days with four moults. The first stage larva is light dusty coloured with greenish tinge, with a few small hairs on the body, measuring 2.5 to 3 mm in length. Each body segment is encircled by a single ring of hairs arising from a pad-like structure, viz., verrucae. The verrucae are arranged in such a way that they appear to form a splitted circular whorl of barbed hairs. The second stage larva is pink, measuring 7 to 7.6 mm. The second stage lasts for six days. The third stage larva has a deeper colour and is covered with long hairs. The size varies from 11 to 11.6 mm. It lasts for about six to seven days. The fourth and fifth stage larvae are deeper in colour with a woolly appearance. Full gown larvae measure 28 mm.

Pupa: Pupation take place after five weeks of hatching in a cocoon of scanty silk and felted hairs discarded by the larva. The pupa is copper brown in colour and the pupal duration is about 10–12 days.

Imago: Both the sexes are brilliantly coloured, male being somewhat lighter in colour, relatively smaller in size with narrow wings and slender abdomen with parallel sides. The anterior half of each segment carries black scales while the posterior portion carries white hairs giving a banded appearance.

12.2.4 **Ceryx godarti,** Bdv: Ceryx godarti belonging to the family Syntomidae is recorded as the minor pest of mulberry in Karnataka (India).

Life cycle and habit: Eggs: A female lays about 200 eggs. The eggs are laid on the lower surface of the tender leaves. They are round and pale yellow in colour and carry polygonal chorian markings and hatch out in five days.

Larva: The larval duration is 30 days. There are four moults before they undergo pupation. The larvae that hatch out are light brown in colour with thick pinkish red verrucae bearing hairs on them in all the segments. The hairs are armed with spiny processes. The head is dark in colour. The first moult takes place after six days of hatching. The second instar larva is dark brown in colour and measures 4.5 mm. The final stage larva is clothested in a thick hairy covering. The colour of larva is almost black and it measures 22 mm. The larva is diurnal in habit.

Pupa: Pupation takes place under the dry leaves and in a thin flabby cocoon made out of its hairs and secreted silk. The pupae are copper brown in colour with a few scattered hairs on the dorsal sides of the cephalic and thoracic regions. A pale yellow narrow band is present immediately under the wing bud on dorsal side. Pupation lasts 13 days.

Imago: The male moths are smaller in size with a narrow abdomen and wings. They measure 12–13 mm in body length with a wing span of 28–29 mm. The female is stouter. The antennae in both the sexes are alike being multisegmented and monoliform. In the forewing six clear areas lacking scales are present. The hind–wing is very small and more or less oblong in shape. Three clear areas are also noted in the wing. The moths are very active and they are found to be diurnal in habit.

Euproctis fraterna, M: it is commonly known as tussock caterpillar of the Lymantridae family. The larvae eat the leaves of the mulberry plants. It is a common pest on many of the food plants grown in tropical countries during the season March to August. A moth lays about 100 eggs (Figure 84).

Life history and habit: Eggs: The eggs are oval in shape, pale yellow in colour and are laid on the underside of the tender leaves in small batches. The egg masses generally 25 to 30 in number are covered with anal hairs of the female moth. The incubation period lasts 15–8 days.

Larva: The hatched larvae are yellow in colour with dark tufts of hairs on the second and third abdominal segments. Head is dark crimson in colour. Very long hairy tufts are present on the first thoracic and on the last abdominal segment. The early stage larvae feed from the undersurface of the leaf. The larva completes four moults to reach the final stage. The final stage larva is dark brownish with the presence of large hairy warts measuring 20–25 mm. The first and second abdominal segments have larger warts which give a hump–like appearance. The total larval duration is 60 days.

Pupa: A brown cocoon is formed by the secretion of the silk along with the hairs of the caterpillar. Three spots are visible on wing pad. Hairy growth is seen all over the pupal body. The pupal stage lasts for about 13–15 days.

Imago: The female moths are yellow in colour. Two dark spots are present on the apical angle and two larger ones on cubital angle of the forewing of the female and an additional dark one near the costal margin in the forewing of the male. Mating of the moths takes place within 24–28 hours after emergence. The eggs are laid within 12–24 hours of mating.

Control measures: Spraying mulberry plants with 0.1 percent Dimethyle Dichloro Vinyl phosphate is effective. The leaves can be used for rearing silkworms after third day of spraying.

12.2.6 **Mulberry pyralid** *(Margaronia pyloalis* WALKER): This is a lepidopteran pest commonly known as "Suki–Mushi" occurring in Japan during the beginning of summer and late autumn. They cause extensive damage to mulberry during late autumn. The insect is seen in all parts of Japan specially in the fields nearer to rivers and sea. In warm zones, they complete ten generations a year while in other parts they generally complete four generations. The life cycle completes in a month (Figure 86).

Morphology and habit: Eggs: The female lays about 200 eggs on the margine of the veins of mulberry leaves on its ventral side. The eggs are green in colour flat and spherical, measuring 0.7 mm in diameter. The female is nocturnal laying eggs within six hours of emergence. The incubation period of the egg is five to six days.

Larva: The larva is green in colour, thus the name "green caterpillar". Generally they moult four to five times to reach the final stage when they measure about 18 mm in length. The larvae feeds on the leaves of mulberry and generally bind joining the leaves together causing great loss. In September the larvae crawl down to the surface to make irregular shape of cocoons where they hibernate at the larval stage. The diapausing period varies in the warm and cold zones of Japan causing variation in their outbreak. In the warm zone it is reported to complete nearly 10 generations in a year.

Imago: The moth is dark brown in colour and measures about 2 cm at the wing expanse. The wings carry dark brown stripes on light yellow whitish background.

Control measures: (i) The larvae can be collected during September by spreading straw or paper on the ground around the mulberry tree as they come down to hibernate and burnt or buried. (ii) Spraying of 1 percent BHC or Parathion is effective. The sprayed leaves can be used for rearing after two weeks. (iii) The parasitic wasps *Macrocentrus philippinensis* Ashmead, lay eggs on the larvae of pyralid. The larvae of the wasp grow as parasites which emerge piercing the skin. The larva is also attacked by the Nematode parasite *Nexamernis incramphidis* Steiner. The Pyralid larva is killed when the parasite comes out of the body.

Mulberry tiger moth (*Spilarotia imparilia* Butler): In the months of autumn in Japan this insect causes the leaves to curl up and change to brown colour (Figure 85). But the damage is severe in spring. The life cycle of the insects lasts a year with the larvae undergoing diapause at the IV moult. The larvae which have overwintered begin their activity in early spring and eat up young leaves at the time of bud sprouting and often upset the plans of silkworm rearers at the start. But this insect is ordinarily seen in mulberry fields in small numbers. If they are found in large numbers then the damage is severe. They pupate generally after tenth moult in May. It is a common pest on rice, barley, vegetables and fruit trees.

Morphology and habit: Eggs: The eggs are covered by a cotton like secretion which is light yellowish brown in colour. The female lays about 3000 eggs in one place and usually dies by the side of her eggs. The eggs hatch in seven days.

Larva: The hatched larvae are dark grey at first, soon turning black. Many tubercles on the body show deep lustrous indigo colour. The larvae spin thread to bind the leaves and gather in them to eat the leaves. When the leaves are eaten up they move to other trees. By November they reach fourth instar. When the atmospheric temperature drops and leaves fall off, they come down the trees to burrow at the base and spin thread to spend winter in a large group. On a warm day near the end of winter they come out of the nest to eat the buds of mulberry which have yet to sprout. In March and April their movements become active and cause severe damage. By the end of May, they moult about ten times become fully grown larvae of six cm long. Then they move down to the ground level to make irregular shaped cocoons in which they pupate. These pupae become adults in course of time.

Imago: The female moths is yellow in colour and has deep brown spots on the forewing. Male is dark brown in colour with blackspots on the forewings.

Control Measures: (i) Mechanical means of destroying egg masses and larvae is commonly adopted. The leaves bound by and containing many larvae can be easily identified and destroyed. (ii) Spraying with BHC is recommended, except during silkworm rearing season. During the rearing season, spraying with 0.05 percent folidol solution is better. In this case the treated leaves must not be used for rearing within 10 days.

Coleoptera

12.2.8: **Mulberry borer** (Apriona Japonica THOMSON): This borer is found in Japan. It causes extensive damage to the stem by laying eggs in tunnels. The young ones grow at the expense of xylem causing the plant to wilt and die.

Morphology and habit: The adult measures 14 cms in length and is dark brown in colour, with whiplike antennae (Figure 90).

Eggs: The eggs are light yellow in colour and long elliptical in shape, measuring 6 mm in length. They take ten days to hatch.

The imago gnaws the epidermis of green wood. It bites at xylem and makes a long thin groove where it lays eggs one at a time. The imago lives for several months and lays about 120 eggs. The grub is milky white colour without thoracic legs. It gradually descends the xylem, bites a hole in the epidermis and enters the ground. In the second year it ascends the tree again, inflicts injuries on the tree, becomes a pupa, then an imago, before it comes out of the ground. Generally, one generation requires two years.

Control: Generally the insect is controlled by collecting and killing the imagos. The place of egg deposition should be sought and the larvae found should be killed. Spraying of insecticides can also be followed.

12.2.9 **Stem girdler** (*Sthenias grisator,* F:) The mulberry stem girdling beetle belonging to the family Cerambycidae is commonly found in India. The destruction is by way of girdling the young or green branches of the mulberry plants. The damage is done during night time, to allow the girdled branches to dry up so as to enable the grubs to tunnel into the dry wood. The bark and wood up to the centre are cut by the powerful mandibles and at times the entire branch becomes cut into two bits. The life cycle is completed in about a year (Figure 87).

12.2.10 **Xylotre chinensis Chevrolant:** This is a common borer found in Japan causing damage to the mulberry trees. They cut the cambium portion of the tree by biting, causing new branches to wither and die.

12.2.11 **Powder pest beetle** (*Sinoxylon pubens*): This belongs to the family Lyctidae. Because of the characteristic presence of the white powdery substance exuded from the stem holes caused by the pest, it is known as powder pest beetle. The affected stem is gradually killed due to the tunnelling by this insect.

12.2.12: **Myllocerus species:** They belong to the family Curculionidae and the different species of this genus recorded on mulberry in India are (i) M. postfasciatus, M., (ii) M. discolour, D (iii) M. subfasciatus, G. and (iv) M. viridanus. They eat the leaves and tender shoots.

Homoptera

12.2.13 **Jassids:** These are popularly known as "leaf hoppers."

Emposca flavescens, Fb. is the species belonging to the family Jassidue of the Hemoptera order. The attack of the hoppers is very severe on mulberry in India during October to May.

The little greenish hoppers feed on the underside of the leaf, sucking the sap from the veins and causing the characteristic symptoms known as "hopper burn". It is reported that the cause of hopper burn is due to a toxic virus for which this insect is a vector. The first symptom of this appears as a triangular brown spot at the tip of the leaf. Similar triangles appear at the end of each vein or the entire margin may roll upward and turn down at one time, as though scorched by fire or drought. These brown margins increase in width until only a narrow strip of the leaf along with the mid–rib remains green, the rest is shivelled and dead, with the leaf veins much distorted. The leaves below the growing tips usually burn first (Figure 92).

Morphology and habit: Eggs: The female lays pale yellow coloured elongated eggs in the epidermis under the leaf blade. The eggs hatchout within ten days.

Nymph: The nymphs are similar in shape to the adults, but lack the wings and are very small and pale green coloured. They usually complete their growth on the leaf where they hatch, feeding from the underside. The colour of the insect as also the activity of the nymphs increase as they shed their skins. The nymphs move characteristically, run sideways over the edge of the leaf to the side.

Imago: The adults are small green winged insects measuring 2.5 to 4 mm in length. They are elongated tapering towards posterior side. The adults fly or jump when disturbed.

Control: Sprinkler irrigation is effective in controlling the pest. Spraying 0.05 percent D.D.V.P. is also effective. Safety period for feeding the leaves for silkworm rearing after spraying is three days. 0.1 percent rogor is also effective in controlling jassids. However, the leaves should be used for feeding silkworms ten days after spraying.

Hemiptera

12.2.14: **Pentatomidae bugs:**

(1) ***Eusarcocoris ventralis,*** W. is found on the mulberry mostly in hilly areas of India. They are very small in size with a brownish tinge. Two prominent spots are visible on the pronotum. They suck the sap from the tender buds and leaves.

(2) ***Nezara virudula,*** L. This is another pentatomidae bug found in fairly large numbers, large in size and greenish in colour. The species suck the sap from the leaf and tender stems and thus damage the quality of the crop.

The pentatomidae bugs are commonly found on other field crops in hill tracks.

Pseudococcidae

Maconellicoccus hissutus

These are popularly called Mealy Bugs. These insects are vectors of the virus disease. *Maconellicoccus hissutus* is a common Mealy Bug on mulberry in tropical conditions and cause the serious "Tukra disease" in West Bengal. The mulberry plants affected by "Tukra disease" show curling of leaves at the growing point and the plant is dwarfed owing to the arrested growth of the plant.

12.2.15 **Mulberry scale insects:** Scale insects belonging to Hemiptera are of different types, such as red and black. Generally when these insects are in small numbers, the damage caused is negligible. However, since these insects are fast breeders the population multiplies causing damage to the plant. When the attack is severe the branches dry and leaves turn yellow and finally the plant dies. Usually the scale insects are common in hilly regions of India and in Japan. The three major scale insect pests are (i) *Pseudaulacapsis pentagona* Targioni Tozzetti in Japan, (ii) *Saissetia nigra* (black scale) and (iii) *Aonidella aurantii* (red scale) of India.

(i)***Pseudaulacaspis Pentagona*** (Figure 88): The female adult is whitish grey coloured and sticks to the branches firmly giving the appearance of grey dots all over the branch. Usually the female is covered by a thick covering, which gives a whitish appearance. During egg laying, the body turns orange red in colour and the shell raises. A female lays approximately 200 eggs, which are oval in shape and yellow in colour. The egg of light yellow colour become female insects while white coloured ones the male. While the female is firmly fixed to the surface of the plant, the male can fly. The females generally hibernate. The eggs hatch in about seven days. The larvae, after crawling out of the female body, sticks to the surface of the plant and start growing. The male insects after attacking the plant develop as adults, but the lifespan of males is only a day or two. Generally both the sexes do not live together. Even though the adult lays eggs soon after copulation, parthenogenesis is not ruled out.

(ii) **Black scales** (*Saissetia nigra,* N.): It belongs to the family Coccidae. It occurs on the stem and branches and also as small scales on the bark. Usually it is more prevalent in hilly regions of India, especially on large and medium sized trees and very rarely on bushes (Figure 89). They suck the cell sap and kill the plants. The surface of the attacked stems are covered all over with scales. The lenticels are completely hidden, and so the respirative rate of the plant cells are considerably lowered.

This pest is controlled by smearing or spraying diesel oil, soap solution or rosin compounds on the plant parts.

(iii) **Red scale** (*Aonidella aurantii,* Mask.): A well known pest of citrus has been found to attack mulberry in some of the hilly areas of India. It attacks the twigs, branches and stems, causing loss of vitality. The maximum damage done by this insect is during the first one and a half years of planting. It does not attack the older plants. In the case of heavy attack of young plants, the leaves become yellow, finally the whole plant dries up and dies. The plant shoots, when heavily attacked, are covered with reddish brown scales, with dark patches of sooty mould which grows on honey dew secreted by the insects. At times the attack causes 15 to 20 percent damage to the young plants.

Prevention and control measures: (1) The stem cuttings for clonal propagation should only be taken from the shoots which are free from the attack of scales. (ii) The infested shoots should be cut and burnt. (iii) Release of predator Coccinellid — *chilochorus kuwanae* is helpful as a measure of biological control. (iv) Spreading of parasitic fungus *Attractium indicum* is also helpful. (v) Spraying lime sulphur solution is effective in reducing the incidence.

Diptera

12.2.16 **Mulberry shoot gallmidge:** *Diplosis mori* YOKOYAMA: It is a dipteran pest found in Japan, 2cm long. Though it belongs to the group of gall midges the larva does not make a gall, but lives near the tip where the new leaves are overlapped and eats the growing part. This often results in stunted or abnormal growth of the shoots. They complete about six life cycles a year.

Morphology and habits: Eggs: The adults are active during night time in June. Its mobility is poor and it usually flies around or near the tree of its emergence. The female lays eggs near the top bud or on the under surface of the newly opened leaf. About 50 eggs are laid by the female. The eggs are oval, milky white, 0.2 mm long, and hatch in a day or two.

Maggots: In five to ten days the maggots become 2 mm and when matured they are vermillion coloured. It makes a cocoon beneath the soil and the cocoon is approximately 2 mm, rough, oval shaped, white coloured and attached with granules of soil all over.

Pupa: The pupa is dark brown, with two horn–like bristles. It lasts four to ten days and emerges out as an adult. The damage is mostly done during July and mid–August.

Adult: The adult is about 2 mm in length and light reddish in colour.

Control: BHC, DDT or Folidol are found to be effective in killing the pest. The leaves can be utilized for rearing silkworms after about 10 days safety period.

Thysonoptera

12.2.17 **Thrips:** Five different species of thrips have been reported to cause damage to mulberry plants in India. The attack of thrips is frequent during the summer season between February to June, and is very severe in rainfed gardens in Karnataka (India) as compared to the irrigated conditions. The attack is negligible in Kolar area of Karnataka where whole shoot harvest is practised. The five species of thrips commonly found on mulberry are:–

i) Psuedodendropthrips mori — NAWA (Figure 91);
ii) Taeniothripsclaratris — SHUMSHER;
iii) Taeniothripsglycines — OKAMOTO;
iv) Haplothripscoloratus — TRYBOM;
v) Taeniothripsmelanicornis — SHUMSHER.

Morphology and habitat: Eggs: The female thrips lay nearly 30 eggs below the epidermis on the end surface of the leaves. The eggs are bean shaped and pale yellow in colour. The incubation period ranges from six to eight days.

Nymphs: The nymphs are pale green in colour actively moving sucking the juice of the mulberry leaf. They pass four moults to reach the final stage at the end of 15 to 18 days of hatching. The nymphs during third and fourth instars generally prepare for pupation.

Imago: The adults measure 0.9 ml and generally females are bigger in size. The body colour is generally brownish yellow. The females can be identified by their dark brown colour.

Control: Sprinkler irrigation is found to be effective in reducing to a great extent the thrips population as a result of the washing out of the various nymphal stages from the leaves. Coccinellids feed on thrips. Spraying with D.D.V.P. at the concentration of 0.02 percent is effective. Sprayed leaves can be used for rearing silkworms after three days interval.

12.2.18 **Mites:** They belong to the class *Arachnoidea* of the order Acarina. Two species are found to attack mulberry and they are (i) *Tetranychus equitorius McGr.* and (ii) *Tetranychus telarius* L.

The leaves of the plants infested by the spider mites present a sickly appearance. Those lightly infested have pale spots throughout the leaf blade. If severe, the entire leaf appears rusty and light in colour and later dries up. The underside of the infested leaf shows silkworm thread spun across them under which the mites crawl and also fasten their eggs. The mites feed through sucking mouth parts with which it pierces the leaf epidermis.

Morphology and habitat: The female lays 2–10 eggs per day and a total of 70–75 eggs are laid. The eggs are spherical in shape, very minute and are usually attached to the under surface of the leaf, within the web. The incubation period lasts from four to eight days. The young ones are pink in colour. Later they moult into proto–nymph, then to deutonymph and to the adult. The female moults thrice, while the males only twice. Usually, one generation is completed within 18 to 40 days, though several overlapping generations are common. Heavy infestation is usually noted during dry hot seasons of the year.

Control: (i) Sprinkler irrigation is effective in reducing the pest incidence. (ii) Coccinellids are found to be predacious upon the mites. (iii) Use of parathion aerosol is effective. Dusting with sulphur is also effective.

12.2.19 **Nematodes:** (1) ***Meloidogyne incognita*:** This is a root–knot nematode recorded on mulberry in India. The infested plants are found chlorotic and stunted in growth. The chief diagnostic symptom is the presence of small knots in the roots. The female is pear shaped with an egg sac. Encysted young males are present in the root knots.

(2) **Meloidogyne arenaria** NEAL: This species is found in Japan. The young nematode after being hatched, gets under the ground penetrates into the root and grows up while making a root–knot. The roots swell up and lose their fucntion of absorbing nutrients. Vitality of the plants deteriorates gradually, and finally the plant wilts.

Control: Treatment of the saplings with DD or Nemagon, a D.B.C.P. preparation is very effective. The infested soil should be replanted after treating with an effective nematicide. Since the root-knot nematodes have several weed hosts it would be necessary to keep the fields free from weeds. When once infested, it is very difficult to eradicate the nematodes from the mulberry field, except by pulling out the plants and treating the soil with nematid fumigants. Newer chemicals which are used in standing crops could also be tried.

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Part IV

FOOD PLANTS OF NON-MULBERRY SILKWORMS

Chapter 13

FOOD PLANTS

13.1 **Introduction:** The "wild silks" comprise *Tasar, Muga, Eri, Anaphe, Fagara, Sinew, Mussel, Spider* and *Coan*. The non-mulberry silk production is mainly by *Antheraea mylitta,* D, *A. pernyi,* G., *A. yamamai,* G. (Tasar); *A. assamensis,* Ww. (muga) and *Philosamia ricini,* Bsd. (Eri). It has also been demonstrated that interspecific hybridization in this genus is possible, Jolly and his associates working at the Central Tasar Research Station, Ranchi have successfully crossed *A. royilei* and *A. pernyi* and the hybrid (*A. proylei*?) is being exploited for commercial silk production in the sub-Himalayan Oak belt of India. The muga silk production is closely related to tasar in that it is produced by another species of silkworm belonging to the same genus (Jolly, Sen and Ahsan, 1974).

Although these wild silkworms are polyphagous in nature, there is some preference for food plants. The food plants of first choice are known as "primary" while the others as "secondary". Though there have been certain scientific curiosity in the non-mulberry silks for several decades in the past, it is with the establishment of the Central Tasar Research Station at Ranchi (Bihar) by Central Silk Board in 1964, that the vast scope for its scientific development in this field becomes evident. The First International Seminar exclusively on non-mulberry silks held in October, 1974 at Ranchi has given a fillip for rapid development of this branch of sericulture. The salient features of the food plants of non-mulberry silkworms are described hereunder.

13.2 **Distribution**

13.2.1 **Tasar:** The Indian tasar silk industry can be differentiated into three distinct entitles viz., (i) tropical tasar, (ii) temperate tasar and (iii) muga. The tropical tasar is dominated by the host plants, *Terminalia* and *Shorea,* the temperate tasar by *Quercus* and the muga by *Machilus* and *Litsaea.*

The food plants of tropical tasar silkworm grow luxuriantly at low altitudes (up to 600 metres above the mean sea level), extending mainly up to torrid zone (23 ½^{0}N and 23½^{0}S latitudes) and rather sparsely up to 40^0 latitude in either direction (Figure 94).

The genus *Terminalia* consists of more than a dozen species occurring in Sri Lanka, India, Burma, Laos and Cambodia and extending through Indonesia, Malaysia, New Guinea up to Australia. The notable of them are, *T. tomentosa, T. arjuna, T. chebula, T. belerica, T. catappa* and *paniculata.* (Figure 93). Some of these species are also reported from the African continent.

In India, *T. tomentosa* is the most important food plant of tropical tasar silkworm (Figure 96). On topping it throws several shoots which remain weak unless thinned out. Under unfavourable agro-climatic conditions the seedlings take as long as twenty years to form a sizeable tree. *T. tomentosa* var. *nepalensis, Ujar-Ki-Asan,* Th. is characterized by its large and oblong leaves and grows at lower elevations in North India, extending up to Nepal, whereas *typica,* Clarke with elliptic-oblong or ovate leaves is prevalent in south Bihar, Orissa and Madhya Pradesh. There are other variants, including a glabrous one found in Santhal Pargana. There are also a few others which appear to be inter-specific hybrids with T. *arjuna.*

T. arjuna is a quick growing plant and is commonly found along streams and river beds in Madhya Pradesh and southern Bihar (Figure 95). In respect of leaf quality, this species is considered on par with *T. tomentosa*. It is also found to occupy the valleys of drier hilly tracts in India, but rarely found in Santhal Pargana, Puri, Cuttack and Balasore. *T. catappa* is commonly found to occupy the temperate, humid zones in the sub-Himalayan belt, whereas *T. belerica* is well distributed throughout India and in the far eastern countries, inside Sal (*S. robusta*) forests.

The genus *Shorea* consists of half a dozen better known species viz., *S. tailura, S. vulgaris, S. cochinchinensis, S. thorelli, S. obtusa, S. hypochlora* and *S. robusta. S. robusta* is abundant throughout the world and provides a rich base for nature grown tasar cocoons. In India, it is widespread except the low lying tracts of the Indo-Gangetic plain. It grows at high elevations and also occurs in Puri in Orissa State and other high grounds in coastal areas. When tapped, the tree yields large quantities of a white resin which is used in Hindu religious ceremonies.

Among the secondary food plants the Ber (*Zizyphus spp.*) is important. This is said to be indigenous to India, Burma and Malaysia. It is widely grown in the plains of Uttar Pradesh, Maharashtra and Rajasthan.

The centre of origin for Jamun (*Syzygium cuminii*) is considered to be India or Indonesia. It also occurs in Madagascar, the Philippines and other countries in the Far East. In India, it is grown throughout from Indo-Gangetic plains in the north, extending up to Tamil Nadu in the South.

Sidha (*Lagerstroemia parviflora*) is more common in India, Burma, Laos, Cambodia and the Republic of South Vietnam. In India it is found all over the sub-Himalayan region, Assam, Bengal, Bihar, Madhya Pradesh, Orissa and Maharashtra.

The original home of fig (Ficus sps) is believed to be southern Arabia, from where it has spread to the mediterranean zone, especially Italy, Spain, Turkey, Greece, Portugal and Algeria. The wild fig is grown all over India, particularly in Poona (Maharashtra), Karnataka, Uttar Pradesh and Bihar.

The temperate tasar includes mainly oaks. The genus *Quercus,* commonly known as oak, comprises nearly 300 species, widely distributed throughout the temperate regions of northern hemisphere and extending up to tropics and sub-tropics of South America, India and Malya (growing at altitudes of 600 metres and above).

In India, the genus is distributed along the western sub-Himalayan range between altitudes of 1200 to 2200 metres and in the eastern hilly tracts between 700 to 1500 metres. The former covers in its stretch the States of Jammu and Kashmir, Uttar Pradesh and Himachal Pradesh, while the latter includes Assam, Meghalaya, Arunachal, Nagaland and Manipur. The oak flora of the former region consists mainly of *Q. incana, Q. ilex, Q. glauca, Q.semicarpifolia* and *Q. himalayana* where as the flora of the easternbelt are *Q. serrata, Q. semiserrata* and *Q. dealbata.* The foliage of the western flora are early maturing, except that of *Q. himalayana,* and the foliage of the eastern flora are generally late maturing (Jolly et al., 1974).

13.2.2 **Muga:** Som (*Machilus bombycina*) and *Soalu (Litsaea polyantha),* the principal food plants of muga silkworm grow abundantly in India, Nepal, Burma, Cambodia, Malaysia and Indonesia. In India, these plants are commonly found in Assam, Meghalaya, Arunachal Pradesh, Tripura, Nagaland, Manipur and North Bengal. Siltimber (*Litsaea* citrata) another food plant of importance is found throughout the sub-Himalayan belt, West Duars, Khasi hills, Cachar and Dibrugarh. Som plants are classified on the basis of leaf shape, viz., *Naharpatiya, Azarpatiya* and *Jampatiya.* The causes of Naharpatiya are considered best suited for muga silk.

13.2.3 **Eri:** Castor (*Ricinus communis*) is believed to have originated from India and Africa. It is grown in many parts of the world such as Sudan, U.A.R., Brazil, United States, Mexico, India, Burma, Sri Lanka, Malaysia, the Phillipines and Indonesia. In India Andhra Pradesh accounts for about 50 percent of the area under this annual crop, whereas the other important States cultivating this crop are Maharashtra, Assam and Karnataka. *Aruna* and *EB16* are the two important castor cultivars recommended for ericulture. Among others TMV–1, a drought resistant variety W.B.1, a dwarf non–shattering type, *M.C.1* and *Roxy*, suitable for red and black soils respectively are worth mentioning.

13.3 **Primary food plants — taxonomy:** As already stated, *Antheraea mylitta*, D. feeds primarily on Asan (*T. tomentosa*, W & A), Arjun (*T. arjuna*, Bedd.) and Sal (*S. robusta*, Gaertn.), while A. proylei (?) J. is mainly reared on Banj (*Q. serrata*, Thunb.) and Moru (*Q. himalayana*, Bahadur). The golden yellow muga silk is secreted by *Antheraea assamensis*, Ww, in Brahmaputra valley on Som (*Machilus bombycina*, King. *M. odoratissima* Nees.) and Soalu (*Litsaea polyantha*, Juss.), while the brick red or white eri silk is produced by *Philosamia ricini*, Bsd. a domesticated multivoltine silkworm, feeding mainly on castor (*Ricinus communis*, L.) and Kesseru (*Heteropanax fragrans*, Seem.). Being important for the industry the primary food plants merit elaborate description.

13.3.1 **Tasar food plants:** *Terminalia*, Roxb. (Figure 96). (Ord. Myriales: Fam: Combretaceae). Habit and habitat — large, deciduous tree, leaf — simple, alternate or sub–opposite, entire, petiolate, often with 1–2 glands on either side. Flower: small, dull yellow, sessile, bisexual, incomplete (Figure 97). Calyx — sepals — 5, petaloid, tube produced over the ovary with constricted mouth; Corolla — petal O; Androecium — stamens 5 + 5, inserted on the calyx tube in two rows; Gynaecium — ovary inferior, pendulous, one celled, ovule - 2–3. Fruit — 3–6 cm long, a coraceous drupe. Seed — exalbuminous, Fleshy, oily. Sprouting — March to April. Flowering — April to June. Fruiting — December to February.

13.3.1.2 **Shorea, Roxb.** (Figure 98) (Ord: parietales; Farm: Dipterocarpaceae). Habit and habitat — large, deciduous tree. Leaf — alternate, simple, stipulate, ovate, oblong, acuminate, tough, glabrous and shining when fully mature, entire, lateral nerves 12–15 pairs. Flower — regular, bisexual, sub–sessile, terminal or axillary racemose panicles (Figure 99). Corolla — petals 5, pale yellow, twisted, much exceeding the calyx, Androecium + stamens numerous, many times shorter thar. the petals, half perigynous or hypogynous connective subulate; gynaeceum — ovary, 3–celled, style subulate. Fruit — 10–12 cm long, edible, ovoid, acute, fleshy, indehiscent, 5–winged, wings — 5–9 cm long, spathulate, narrowed at the base, brown when dry, somewhat unequal with 10–12 straight parallel nerves. Germination — hypogeal. Sprouting — February to March. Flowering — March to April. Fruiting — May to July.

13.3.1.3 **Quercus,** L. (Figure 100) (Ord. Fagales, Fam: Fagaceae). Habit and habitat — large, evergreen, deciduous or sub–deciduous tree. Leaf — alternate, generally serrate. Flower — unisexual, incomplete, monoecious, male generally in drooping spikes (Figure 101a and 101b). Perianth 4–6 lobed, lobes imbricate; Androecium — stamens 6–12 or many, filaments — slender; female — solitary in cluster or short spikes enclosed in an involucre of bracts, perianth adnate to the ovary; Gynaeceum — ovary 3–5 celled with two ovules in each cell, styles 3–5. Fruit — nut, edible. Seed — 1–2, thick, fleshy, cotyledons. Sprouting — May to June. Flowering — April to May. Fruiting — usualy winter season.

13.3.2 **Muga food plants:**

13.3.2.1 ***Machilus,*** Nees. (Ord: Laurales; Fam: Lauraceae). Habit and habitat — evergreen trees — leaves — alternate, simple, ex–stipulate generally entire, penninerved, flowers — regular, incomplete, bisexual in axillary and terminal panicles; Perianth — divided to the base, segments — 6, imbricate in bud, persistent; Androecium — perfect stamens 9, the 6 outer eglandular with 4 celled anthers opening inwards, the inner three with 2 glands at the base and 4 celled anthers opening outwards; the innermost of fourth series of 3 short staminodes, perigynous; Gynaeceum — ovary syncarpous, superior, 1 celled, ovule — solitary, pendulous, anatropous, Fruit — berry (globose or oblong). Seed — pendulous, exalbuminous, pedicel not swollen. Seed — exalbuminous. Flowering — March to May. Fruiting — May to July.

13.3.2.2 ***Litsaea,*** Lamk. Habit and habitat — evergreen trees. Leaves alternate, elliptic ovate, oblong or lanceolate, acute or acuminate. Flowers — dioecious, in few sessile or pedicellate umbels, incomplete, bisexual; Perianth — tubular, 4-6 lobed; Androecium — stamens — 13, those of the inner series with a pair of glands at the base, anthers 4-celled, introse-perigynous; Gynaeceum — ovary superior, syncarpous, 1-celled, ovule solitary, pendulous. Fruit — drupe. Seed — pendulous, exalbuminous. Flowering — March to May. Fruiting — September to December.

13.3.3 **Eri foodplants:**

13.3.3.1 ***Ricinus communis,*** L (Figure 102) (Vern. Bharenda. Ord: Euphorbiales, Fam: Euphorbiaceae). Habit and habitat — an evergreen shurb, annuals, biennials, perennials. Leaves — simple, alternate. Inflorescence a terminal receme. Flowers — small, incomplete, actinomorphic, hypogynous, unisexual, monoecious, upper female and lower male; Perianth in 3-5 whorls, united (Figure 103a and 013b); male flowers — stamens many, polyadelphous; female flowers — carpels-3, united, connate, ovary 3-lobed and 3-celled with one ovule in each cell, styles - 3, bifid, long or short stigma-6. Fruit — a globose capsule, generally echinate. Seed albuminous. Germination epigeal. Flowering most part of the year.

This is an important oilseed crop of India yielding valuable oil and the cake left over after the oil is extracted is used as organic manure. The rainfed crop yields about 2-5 q. of oil per seed per ha, whereas an irrigated crop yields 5-8 q. per ha. When raised for ericulture, the rainfed crop yields on an average 140 q. of foliage and 1-3 q. of seed per ha. Its use in Assam, Meghalaya, Arunachal Pradesh, Manipur and Tripura is mainly for ericulture. In these tracts castor is grown as a self-generated crop on hill slopes, field bunds and other fallowlands, assuming a perennial habit. This is in sharp contrast with Andhra Pradesh, Maharashtra and Karnataka where it is grown as an annual crop, solely for oil, accounting for about 80 percent of total production in India.

13.3.3.2 **Heteropanax fragrans,** Seem. (Vern. Kesseru: Ord. Umbellales/Araliales; Fam: Araliaceae). Habit and habitat — a small, erect, evergreen tree. Leaves — tripinnate, 2-4 ft. long and 2-3 ft. wide, petiolate, stipules minute. Leaflets 3-5, ovate or elliptic, short acuminate, narrowed at the base, entire, glabrous. Panicles about 90 cm long umbel bearing racemes, sub-capitate. Flowers — small, yellow, fragrant, bisexual, epigynous, polygamous; calyx — nearly truncate; corolla-petals 5, valvate; Androecium — stamens 5 alternating with petals, filaments inflexed, anthers versatile; Gynaeceum — ovary 2-celled, styles 2, filiform, inferior, ovules solitary, pendulous. Fruit — compressed. Seeds — 2. Flowering — January to February. Fruiting — February to March.

13.4 **Secondary food plants:** Systematic position

The following secondary food plants of non-mulberry silkworms are considered important:

13.4.1: **Tasar**

13.4.1.1: **Tropical tasar:**

Ord: Myrtales: Fam: Combretaceae

1. *Terminalia chebula,* Retz. (Vern. Haritaki);
2. *T. belerica,* Gaertn. (Vern. Bahera);
3. *T. catappa.* L. (Vern. Jangalibadam);
4. *T. paniculata,* Roth. (Vern. Kinjal);
5. *Anogeissus latifolia,* Wall. (Vern. Dhaunta);

Ord: Myratales; Fam: Myrtaceae

6. *Syzigium cuminii.* Skeels. (vern. Jamun);
7. *Careya arborea,* Roxb. (Vern. Kumbi);

Ord: Mytrales; Fam:Lythraceae

8. *Lagerstroemia parviflora,* Roxb. (Vern. Sidha);
9. *L. indica,* Linn. (Vern. Saoni);

Ord: Myrtales; Fam: Melostomaceae

10. *Melostoma malabthricum,* L. (Vern. Phutki);
11. *Zizyphus jujuba,* Mill. (Vern. Ber);
12. *Z. rugosa,* Lam. (Vern. Bhand)
13. *Z. xylopyra.* Willd. (Vern. Kathber);
14. *Z. mauritiana,* Lam. (Vern. Indian Ber or Hevi);

Ord: Lamiales; Fam: Verbenaceae

15. Tectona grandis, L.f. (Vern. Sagwan)

Ord: Malvales; Fam: Moraceae

16. *Ficus religiosa.* L. (Vern. Pipal);
17. *F. retusa,* L. (Vern. Chilkan);
18. *F. tseila,* Roxb.

Ord: Parietales: Fam: Dipterocarpaceae

20. *Shorea tailura,* Roxb. (Eng. Lac tree of S. India);

Ord: Gentianles; Fam: Apocynaceae

21. *Carissa carandus,* L. (Vern. Karumcha);

Ord: Geraniales; Fam: Meliaceae

22. *Capadessa fruiticosa,* Blume (Vern. Nalbali);

Ord: Rubiales; Fam: Rubiaceae

23. *Canthium didynum,* Roxb. (Vern. Rangruri);

Ord: Sapindales; Fam: Sapindaceae

24. *Dodonaeae viscosa,* (L.) Jacq. (Vern. Aliar);

Ord: Sapindales; Fam: Sapotaceae

25. *Madhuca indica,* Gmel. (Vern. Mahuxa)

Ord: Rosales; Fam: Laguminosae; Sub-fam: Caesalpinadae

26. *Hardwickia binata,* Roxb. (Vern. Anjan);

27. *Bauhinia variegata,* L. (Vern. Kachar).

13.4.1.2 **Temperate tasar** (Oak based)

Ord: Fagales; Fam: Fagaceae

28. *Quercus aegilops* L. (Valonia oak);

29. *Q. borealis,* Michx. f. (American Red oak);

30. *Q. canariensis,* Willd. (Canary Island oak);

31. *Q. castaneaefolia,* C.A. Mey (Chestnut leaved oak);

32. *Q. cerris,* L (Turkey oak);

33. *Q. coccinea,* Munchh. (Scarlet oak);

34. *Q. frainetto,* Ten. (Hungarian oak);

35. *Q. hispanica,* Lam, var. *lucombeana* (Sweet), Rehd. (Eng. Lucombe oak);

36. *Q. ilex,* L. (Evergreen oak);

37. *Q. libani,* (Lebanon oak);

38. *Q. lusitanica,* Lam. (Lusitanian oak);

39. *Q. palustris,* Munchh. (Pin oak);

40. *Q. petraea,* (Mattuschka) Liebl. (Sessile oak);

41. *Q. reticulatam* Humb and Bonpl. (Net-leaf oak);

42. *Q. robur,* L. (English oak);

43. *Q. suber,* L. (Cork oak);

44. *Q. semicarpifolia,* Smith (Vern. Kharshu);

45. *Q. glauca,* Thunb (Vern. Inai);

46. *Q. acutissima;*

47. *Q. crispula;*

48. *Q. mongolica;*

49. *Q. myrsinaefolia;*

50. *Q. dentata;*

Ord: Salicales; Fam: Saliaceae.

51. *Salix viminalis* (Eng. willow).

13.4.4.2 **Muga**

Ord: Laurales; Fam: Lauraceae

52. *Litsaea citrata,* Blume, (Vern. Sittimber);
53. *L. salicifolia,* Roxb. (Vern. Digloti);
54. *Actinodapline* sps.
55. *Cinnamonum* sps.

Ord: Magnoliales; Fam: Magnoliaceae

56. *Michelia champaca,* Linn (Vern. Chapa)

Ord: Rhammales; Fam: Rhamnaceae

57. *Zizyphus jujuba,* Mill. (Vern. Ber);

Ord: Geraniales: Fam: Rutaceae

58. *Zanthoxylum rhetsa* DC (Vern. Bajramani);

Ord: Lamiales; Fam: Verbenaceae

59. *Gmelina arborea,* Roxb. (Vern. Gambari);

Ord: Celatrales; Fam: Celatraceae

60. *Celastrus monosperma,* L. (Vern. Bhuroti)

13.4.4.3: **Eri**

Ord: Euphorbiales; Fam: Euphorbiaceae

61. *Manihot utilissima,* Pohl. (Vern. Simul–alu);
62. *Jatropa curcas,* Linn (Vern. Bhotera);
63. *Sapium Sps.* P.Br.

Ord: Geraniales; Fam: Simarubaceae

64. *Ailanthus excelsa,* Roxb. (Vern. Maharukh);

Ord: Geraniales; Fam: Rutaceae

65. *Evodia flaxiniflora.* Hook, f. (Vern. Pyam);

Ord: Geraniales; Fam: Caricaceae

66. *Carica papaya,* L. (Vern. Papita);

Ord: Gentianales; Fam: Apocynaceae

67. *Plumeria rubra, L. form acutifolia* (Poir) (Vern. Gulancha).

13.5 Foliar constituents of Tasar food plants: Chemical analysis of the leaves reveal useful information on the nutritional values of food plants of silkworms. This paves the way for selection of suitable food plants species and their varieties and also the appropriate stage at which the leaves are to be harvested. The foliar constituents in a number of tasar food plants have been assayed at the Central Tasar Research Station, Ranchi, and the data are summarized in table.

There exists considerable variation among the food plants in their nutritional constituents. The total nitrogen and crude protein contents of the leaves increase with age, whereas the starch and total sugar contents in most of the food plants get reduced with maturity. It may further be inferred that Asan and Arjun, which have low percentage of crude fibre, together with high percentages of sugars and minerals add to nutritional qualities of the leaves resulting in better tasar silk production.

Table 14

Foliar constituents of Tasar food plants
(Percentage in oven dry basis)

Food plants	Type	Moisture percent	Total Nitrogen %	Crude Protein %	Crude Fibre %	Total Minerals %	Reducing sugar %	Total sugar %	Starch %
Terminalia arjuna	Tender	80.00	1.38	8.61	6.50	6.94	6.01	7.84	14.15
	Medium	73.33	1.59	9.96	8.73	7.84	3.95	5.76	10.58
	Mature	68.57	1.88	11.73	8.10	6.48	2.94	3.65	8.56
Terminalia tomentosa	Tender	75.20	1.57	9.80	10.75	6.49	2.60	8.78	17.25
	Medium	72.28	1.76	11.03	10.38	6.73	2.35	7.77	15.57
	Mature	67.66	1.91	11.94	16.10	8.41	2.21	7.30	12.23
Shorea robusta	Tender	64.33	1.23	7.70	15.68	4.15	5.79	6.45	17.00
	Medium	60.60	1.49	8.80	21.38	4.96	4.92	5.47	11.83
	Mature	58.07	2.03	12.72	21.10	4.37	3.42	4.06	8.61
Quercus serrata	Tender	58.30	1.57	9.81	8.90	3.70	1.29	4.00	10.18
	Medium	57.90	1.62	10.12	11.10	4.00	1.82	4.75	9.27
	Mature	50.00	1.96	11.35	13.70	4.90	2.82	5.62	8.26
Quercus incana	Tender	64.40	1.68	10.50	13.70	5.60	2.58	9.55	17.43
	Medium	55.60	1.74	10.87	14.86	4.70	3.04	10.37	15.52
	Mature	48.80	2.02	12.62	16.73	4.60	3.90	12.90	12.30
Lagerstroemia parviflora	Tender	76.26	1.62	10.15	13.05	5.80	3.24	7.33	12.49
	Medium	70.27	1.79	11.10	23.37	5.56	3.12	6.05	10.99
	Mature	67.40	1.96	12.25	22.43	5.16	2.65	5.16	10.08
Zizyphus mauritiana	Tender	71.34	2.26	14.12	15.73	6.67	2.37	8.78	17.64
	Medium	62.16	2.41	15.06	16.90	7.40	1.88	7.53	17.44
	Mature	60.23	2.71	16.94	14.65	5.92	1.38	6.40	15.43
Syzygium cuminii	Tender	72.12	1.76	11.03	9.06	5.34	2.92	8.46	17.45
	Medium	69.69	2.16	13.47	11.04	4.78	2.69	6.85	15.32
	Mature	67.35	2.32	14.52	18.25	5.82	1.68	5.37	14.93
Terminalia belerica	Tender	78.00	2.41	15.06	7.40	4.90	1.21	3.84	12.70
	Medium	76.50	2.63	16.43	9.01	5.02	1.35	4.78	11.29
	Mature	75.10	2.75	17.18	10.13	5.23	1.39	5.35	9.98
Salmalia malabarica	Tender	80.70	2.34	14.62	8.30	6.66	1.08	3.25	14.31
	Medium	78.50	2.67	16.68	10.10	6.82	1.15	4.13	13.10
	Mature	76.50	2.99	18.69	11.42	6.96	1.20	4.94	12.09
Madhuca indica	Tender	74.00	2.16	13.50	11.18	5.20	1.17	5.67	9.68
	Medium	71.30	2.21	13.81	11.60	5.30	1.74	6.61	8.97
	Mature	66.70	2.44	15.25	16.28	4.96	2.22	7.88	7.66
Bauhinia variegata	Tender	80.00	3.14	19.62	9.75	5.11	1.96	6.77	15.43
	Medium	79.10	3.47	21.68	12.94	5.52	3.00	7.74	14.50
	Mature	77.90	3.64	22.75	19.37	5.90	3.09	10.32	13.81

Chapter 14

ARBORICULTURE

14.1 **Climate and soil:** The non-mulberry silkworm food plants, in general, are relatively more tolerant to drought and grow well in dry and warm climatic conditions, with low rainfall. Castor plants, however, grow luxuriantly in humid tracts, putting forth voluminous vegetative growth. Except oaks, none of the food plants are able to stand frost. Submarginal lands generally are not suitable for most other annual crops including cereals and commercial crops and they could be grown to food plants suited to non-mulberry silkworms. This is particularly true in respect of tasar food plants. Such lands are available in abundance in the developing countries in Asia, Africa and Latin America. Furthermore, in the developing countries labour force is available in plenty to take to this intensive rural based cottage industry. Hence, there is ample scope for development of non-mulberry sericulture in the developing countries particularly in India.

Terminalia and Shorea thrive best in clayey loam soils. However, the food plants in general come up well on almost all types of soils. Red and lateritic soils occupy a majority of traditional tasar tracts in India. Red soils are generally shallow with low base exchange capacity. Lateritic soils are red and well drained. The depth of lateritic morrum layers vary considerably. Usually these soils are poor in plant nutrients but respond well to manuring and irrigation.

Oak flora is found to grow luxuriantly in the soils at the higher elevations all along the temperate sub-Himalayan belt. These soils are characterized by high organic matter content and are either acidic or neutral.

Both castor and cassava grow well in a warm climate and in regions receiving a well distributed rainfall. They grow in almost all soil types but castor comes up well in red sandy loam and light alluvial soils, while cassava flourishes well on red lateritic loam.

14.2 **Preparation of land:** For raising regular plantations, it is desirable to plan systematically, well in advance. The land is prepared by repeated ploughing, disking, levelling and terracing, where necessary. For raising plantations for tasar and muga worms, pits measuring 60 cm x 60 cm x 60 cm are dug at least a fortnight before transplanting. Each pit is filled with 10 kg of farmyard manure or compost, 100 g each of Karanj cake, bonemeal, wood ash, Aldrin 5 percent dust and required quantity of soil. Robust and healthy seedlings/stumps/air-layers should be transplanted during the rainy season. Around each plant, basins are formed and the first irrigation is given immediately after planting. A second irrigation is given after 3–4 days, if no rainfall occurs in between. No further irrigation is necessary, unless severe drought follows planting.

The field meant for castor crop is prepared well by ploughing and harrowing 2–3 times before sowing. Castor seed is sown during June–July, using a seed rate of 7–12 kg/ha in rows 90–150 cm apart, and the crop is thinned after about ten days of sowing, so as to leave one plant at every 60–90 cm in the row. However, the perennial castor crop is given 1.80–2.40 m. spacing in either direction. In the case of fallow lands, green manuring with a leguminous plant will help in improving the fertility level of the soil.

14.3 **Plant propagation:** Propagation from seed is very common with tasar, muga and eri food plants. It is, however, not recommended for commercial plantation with tasar and muga food plants, since the trees raised from the seeds are slow growing, not uniform in growth and in leaf yield and quality. The trees become too large in size for economic management. Therefore, vegetative propagation is to be preferred. This assures quicker plant growth, and also the plants retain the genotype of the parent. Among the several methods of vegetative propagation, stem and root cuttings, inarching and cleft grafting, crown, T and forkert methods of budding, air and ground layerings have been successfully tried in several non-mulberry food plants and they are described in brief.

14.3.1 Cutting

14.3.1.1 **Stem cutting:** Propagation of woody plants by stem cutting was considered difficult until the recent development of mist chamber technique successfully employed in Syzygium (Figure 104). The cuttings of 0.9–1.2 cm thickness and 18–20 cm in length are first treated with appropriate concentrations of indole butyric acid, depending upon the plant species, and then inserted in a slanting position in porous soil. The plant material is then sprayed with fine mist for 45 days at 5–10 second intervals (Bose and Sadhu, 1974). Sagwan has been propagated from stem cuttings after mutilating C/N ratio by ringing. Cassava, a secondary foodplant of Eri worm is generally propagated through stem cuttings. Chowdhury (1974b)reported limited success with clonal propagation of Som and Soalu.

14.3.1.2 **Root Cutting:** Fresh root bits, 10–25 cm long, are cut and buried horizontally in sand/soil at a depth of 7–10 cm. The shoots generally come out within 30–40 days. By using this tool, propagation of Sisam and Sagwan could be made with utmost success. It is possible to propagate Arjun (T. arjuna) by this method.

14.3.2 **Grafting:** The phenomena of grafting is similar to that described in mulberry.

14.3.2.1 **Inarching:** The stock plants, 3–4 years old, raised in plots, are brought near the scion. About 4–5 cm long bark and adjoining tissues from the stem of the stock and scion facing each other are removed. The cut portions are brought together, bound tightly with jute thread, sealed with grafting wax and the trees are irrigated regularly till a complete union is achieved. As soon as the union is complete, the portion of the stock above the union and that of scion below the union are severed as detailed under mulberry propagation. This method is employed in Arjun, Oaks and Jamun.

14.3.2.2 **Cleft grafting:** This is an efficient method of rapid improvement of wild flora, without replanting. The procedure adopted for this grafting is the same as described under mulberry grafting.

14.3.3 **Budding:** This technique involves insertion of a bud inside the bark of the root stock and is considered as one method of grafting. There are three different methods of budding viz., T–budding, Forket and crown budding which are commonly used for propagation of the host plants and the procedures are the same as detailed under mulberry propagation.

14.3.4 **Layering:** Air layering and ground layering as practiced for mulberry are also applicable to the non–mulberry host plants. Arjuna and Som have been successfully propagated by air layering and arjun by ground layering also.

It is highly desirable to test the efficacy of the different methods to make it an economic proposition for any given host plant. However, it is worth mentioning that the methods of budding, grafting and layering are laborious and require considerable technical skill, rendering them less economic than propagation through stem cuttings.

14.4 **Cultural operations:** Tasar, Muga and Eri food plants are seldom manured and irrigated but recent studies carried out in this direction have resulted in considerable increase in foliage production in *T. tomentosa;* the appropriate dose per plant being 20 kg of farmyard manure along with 14 g of Nitrogen and 7 g of P_2O_5 as chemical fertilizers. Chowdhury (1974a, b) laid emphasis on regular manuring of Som, Soalu and Kesseru plantations. He further advocated for an annual dressing of FYM at 21 cubic metres per ha and maintenance of soil, N:P:K ratio at 7:4:1 for muga food plants. He also pointed out the need for maintaining soil pH within a range of 6.0–6.5 by systematic liming, in order to prevent fungal attacks and to restore soil fertility. Green manuring with sunhemp (*Crotolaria juncea,* Linn), dhaincha (*Sesbania aculeata,* Pers.) and horse gram (*Dolichos biflorus.* L) has also been advocated by Jolly et al. (1974) to improve soil fertility in tasar fields.

14.5 **Training and Pruning:** The tasar and muga food plants have a tendency of attaining some heights. However, in order to facilitate rearing, a height of about 2–3 m with well-spread crowns, bearing rich foliage is considered ideal. The modern concept of tasar culture advocates field rearing on systematic man made plantations and it is advisable to train these plants from the very early state of their growth. When a plant is tied, staked or pruned with a view to giving the plant a framework, the operation is called training; whereas, pruning involves periodical removal of annual growths. Pruning is capable of influencing the crop production but not the original framework. Apart from producing a framework suitable for easy rearing systematic training is aimed at regulating sunlight, and air to penetrate the crown to facilitate various cultural operations and to protect the tree from sunburn and wind damage.

Trees can generally be subjected to three systems of training, viz., central leader, open centre and modified leader systems and are described in brief:

14.5.1 **Central leader system:** In this system, the dominance of the main trunk is maintained, while the lateral branches are not allowed to spread, excepting a few scaffolds at regular heights to give the plant a linear shape (Figure 105).

14.5.2 **Open centre system:** In the open centre system, the central axis is never allowed to grow beyond a certain height, thereby inducing all subsequent growth of lateral branches. This results in a crown consisting of several shoots. The branches which come out are very rich in foliage with larger leaves and of better quality. This method has been found to be very essential with Asan and Arjun plants (Figure 106).

14.5.3 **Modified leader system:** The modified leader system is intermediate between the two (Figure 107), where the central axis is allowed to grow for the first 4–5 years, headed back and then 3–5 lateral branches are allowed to grow as in open centre system.

In the Oak belt the tall trees have created hazards only in the western zone in India. This problem can be tackled effectively by applying open centre system or modified leader system. In Manipur, the oaks are generally short, due to large scale ground pruning by local people, for collecting fuel. The leaf quality is another important factor which deserves careful consideration. While the leaves of the spring flush are suitable for raising the first cocoon crop, both in traditional and oak belt, the foliage becomes overmature during the second season in some of the oak species and in Sal. In the traditional belt this problem has been overcome by light pruning and leaf plucking. In an unpublished observation, Jolly and Singh recorded that the light pruning/leaf plucking during April–August in Sal results in sprouting within 18–21 days. These durations increase slowly, from September onwards. Identical experiments conducted on *Q. incana* in Uttar Pradesh have indicated that sprouting takes place in about a month and the foliage is fit for feeding after another 3–4 weeks (Kapila 1974, unpublished). This technique, which provides suitable foliage to early instar larvae is being successfully utilized for second rearing in the western oak belts.

Muga and Eri food plants are usually not pruned. One tipping at the early stage of growth in Som, followed by systematic pruning, leads to a bushy, dwarf tree (Chowdhury, 1974b). The clipping of the primary root at the nursery also induces a busy growth.

14.6 **Block plantation:** In India where both tropical as well as temperate types of tasar culture are being practised, it is estimated that more than 10–15 percent food plants have been utilized so far. Though the modern concept of tasar culture advocates rearing on systematically raised economic plantation described below, in the absence of such a possibility in the immediate future, already existing forest wealth could be utilized to the maximum possible extent.

In order to stimulate interest and also to rationalize the existing practices, exclusive allocation of forest blocks containing Asan and Arjun trees for large scale commercial exploitation can be advocated.

The areas where the food plants are concentrated could be earmarked for intensive tasar rearing. Within this area the non-mulberry food plants could be replaced systematically with primary food plants, thereby substantially increasing the number of plants per unit area. This will pave the way for raising food plants in a compact area and ensure increased foliage production, better management and ultimately high productivity per unit area.

14.7 **Economic plantation:** For centuries now, the rearing of non-mulberry silkworms remained in the hands of tribals and no systematic approach has been made to raise economic plantations. Moreover, in the traditional practice, tasar larvae are being fed on irregularly distributed food plants in forests or in *bunds* of paddy fields. This creates management hazards resulting in heavy losses due to pests, diseases and other natural enemies. A radical change as such is inevitable and recent research conducted at the Central Tasar Research Station, Ranchi, has put forth a new concept, that systematic plantation in the field of tasar is an economically viable proposition (Jolly, Sen and Ahsan, 1974). The experiments to raise economic plantations with *T. arjuna,* a quick growing tasar food plant have indicated that with a decrease in spacing, although the leaf yield per plant goes down, the ultimate yield per unit area goes up substantially, due to increased plant frequency (Figure 108). Therefore, plantations with a closer spacing of about 1.22 m. in either direction, along with agronomical support if raised for non-mulberry sericulture, shall permit better farm management and increase rearer's income manifold for tasar culture as seen from the data in Table 15.

Table 15

Tasar leaf production under different spacing of plants.

Spacing	1.22 m x 1.22 m	1.52 m x 1.52 m	1.83 m x 1.83 m	3.66 m x 3.66 m
Number of plants	6 783	4 303	2 989	755
Leaf yield (metric tons)	17.28	13.08	8.32	3.70

The data on leaf yield given above is based on an experiment conducted at the Central Tasar Research Station, Ranchi, where the soil nitrogen content is poor, coupled with low water holding capacity and pH and high incidence of soil pests. Such soils are not well suited and are uneconomical to raise valuable commercial crops. Similar systematic studies on raising of economic plantations of plants for muga and eri silkworms are lacking.

14.8 **Intercrops and cover crops:** The intercrops are raised to supplement rearer's income. In slopey lands these can also offer considerable protection against soil erosion. It is also suggested to lay emphasis on legumes which can enrich the soil by fixing atmospheric nitrogen, e.g. urid (*Phaseolus mungo,* L.), mung (*P. aureus,* Roxb.), moth bean (*P. aconitifolius,* Jacq,) and horse gram (*Dolichos biflorus,* L.) (Jolly *et al.,* 1974) (Chowdhury, 1974b). Hardy cereals, millets and oil seeds can also be grown with advantage in the soils planted with non-mulberry plants. Such intercrops could bring an additional income of about D.100 per hectare per annum, coupled with a marginal increase in foliage productivity of the primary food plant, *T. arjuna.*

14.9 **Interchange of food plants:** While there is no doubt about the supremacy of Asan and Arjun as food plants of tasar silkworms, the efficacy of Sal as a primary food plant is sometimes doubted. Though Sal can support a satisfactory crop in the first rearing season, in the second season the larvae start dying at the fifth instar stage. It is an *ipso facto* that nature grown Sal cocoons are superior in cocoon weight and silk content than those raised on *Terminalis* (Jolly, Sen and Ahsan, 1974). Therefore, developement of a suitable technique of rearing for proper utilization of Sal would be of immense value to the industry.

Recent research has shown that shifting of the larvae from Asan to Sal just after the fourth moult helps in minimizing the loss and ensures a moderate harvest with quality cocoons. This is of significance as larvae consume about 80 percent of foliage during the fifth instar and Sal grows in abundance throughout the developing countries.

In respect of secondary food plants it is possible to raise a sizeable crop of cocoon on Ber (*Z. jujuba*), Jamun (*S. cuminii*), Sidha (*L. parviflora*) and Kumbi (*C. arborea*), the first one recording the best yield both quantitatively and qualitatively. Attempts to raise. A mylitta crop on Kachar (*B. varietta*), Bahera (*T. belerica*), Hari-taki (*T. chebula*), Mahua (*M. indica*), Sagwan (*T. grandis*), Dhaunta (*A. latifolia*) and Simul (*B. ceiba*) have not met with success under the prevailing Central Indian Agro-climatic conditions. The use of alternative food plants has been reported to increase larval mortality in muga and eri worms, and no data on interchange of food plants for these works are available.

14.10 **Plant protection:** Maintenance of health and vigour of the food plants are of prime significance to harvest a maximum crop. This can be obtained by resorting to adequate field sanitation measures including clean cultivation, manuring, irrigation and other cultural practices. Liberal application of potassic fertilizers would help in building resistance against diseases and pests. Light traps and other chemical attractants can be profitably used to destroy adult insect pests of the host plants. Among the several insect pests attacking the major food plants stem borers, termites and gall fly/wasps are worth mentioning. The stem borers can be controlled by plugging borer holes with cotton soaked in petrol/kerosene/EDCT and the mouth pasted with mud. Liberal application of *Karanj* cake for manuring and incorporation into soil of Aldrin (5 percent dust) at 20 kg/ha is recommended for soils badly infested with termites, May–June beetles and nematodes. Similarly, one spraying with Demecron (0.03 percent) + 0.5 percent Bordeaux mixture (2.5:2.5:50) during every spring flush would offer protection against gall fly, wasps and leaf spot diseases.

In order to control fungal diseases such as stem canker and curly leaf attacking Terminalias, heavy pruning and burning of infected twigs/leaves followed by dressings of cut ends by Bordeaux paste may be adopted. This may be followed by periodical spraying with 0.5 percent Bordeaux mixture, 0.2–0.3 percent Blitox or 0.2 percent Dithane M–45. An interval of 10 days should be given between spraying and feeding the sprayed leaves to the silkworms.

The alternaria blight (Alternaria ricini (Y) Hansford) and seedlings blight (Phytopthora colocasiae, Racib) are two most serious diseases of castor. The former can be easily controlled by adequate seed treatment with Agrosan GN and the latter requires proper soil drainage facilities, coupled with a suitable crop rotation. The castor semi-looper (Achaea janant, L) and the castor hairy caterpillar (*Euproctis lunata,* Wlk.) cause serious losses to the foliage. Spraying the crop with 0.2 percent endrin will give an effective control of these pests and an interval of 15 days should be given between spraying and feeding the worms with the sprayed leaves.

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ILLUSTRATIONS

Volume I — Mulberry Cultivation

Fig. 1

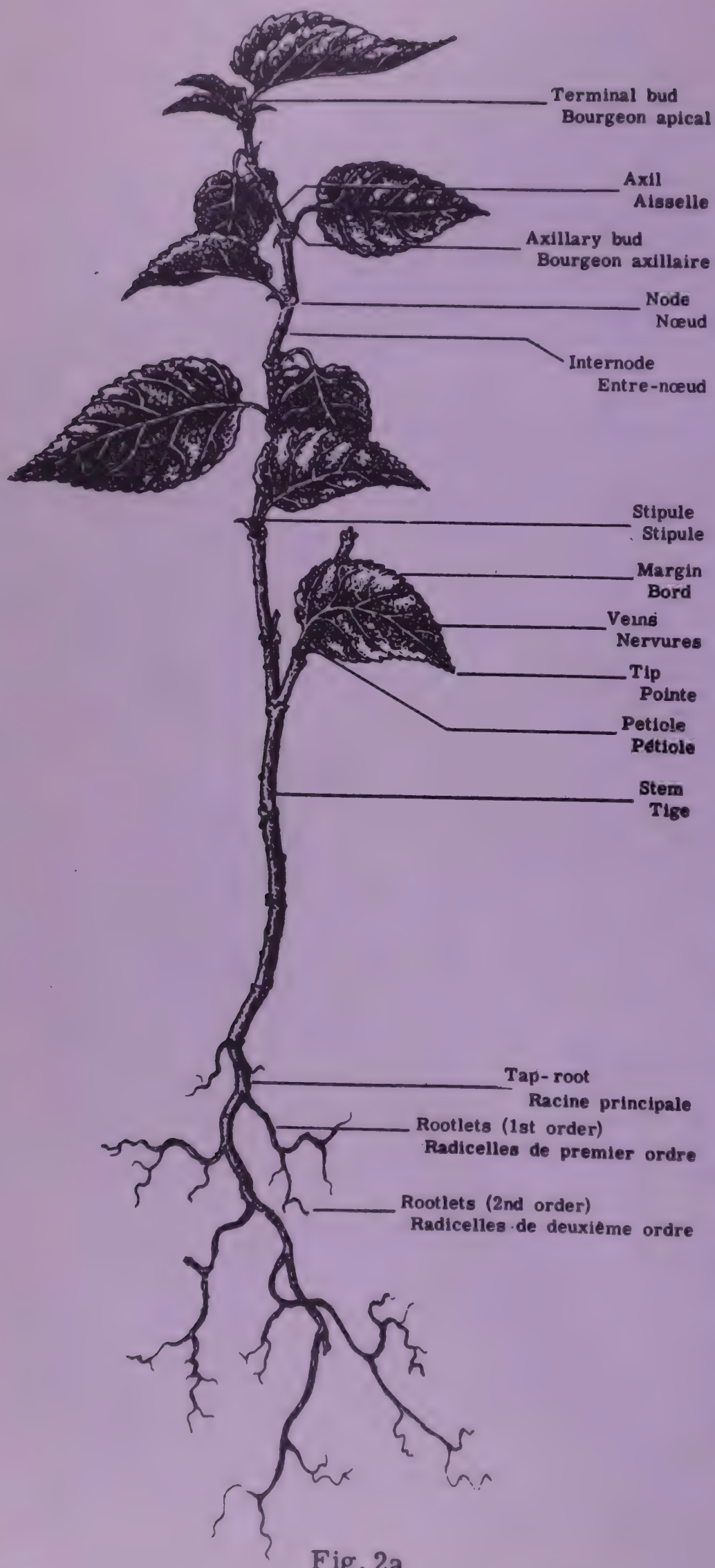


Fig. 2a

Fig. 2b

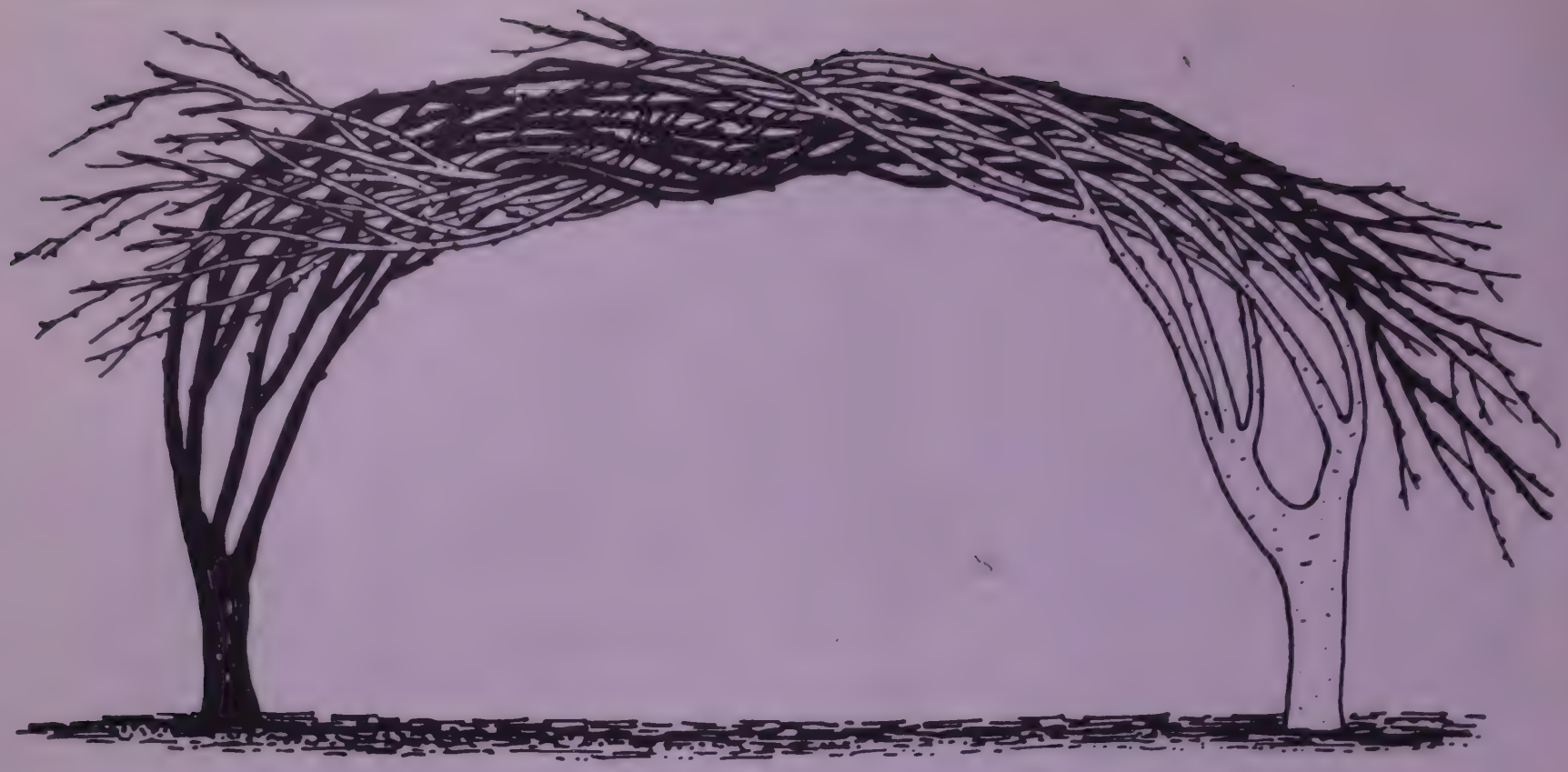
Fig. 2c

Fig. 5

Fig. 6

Fig. 3

Fig. 4



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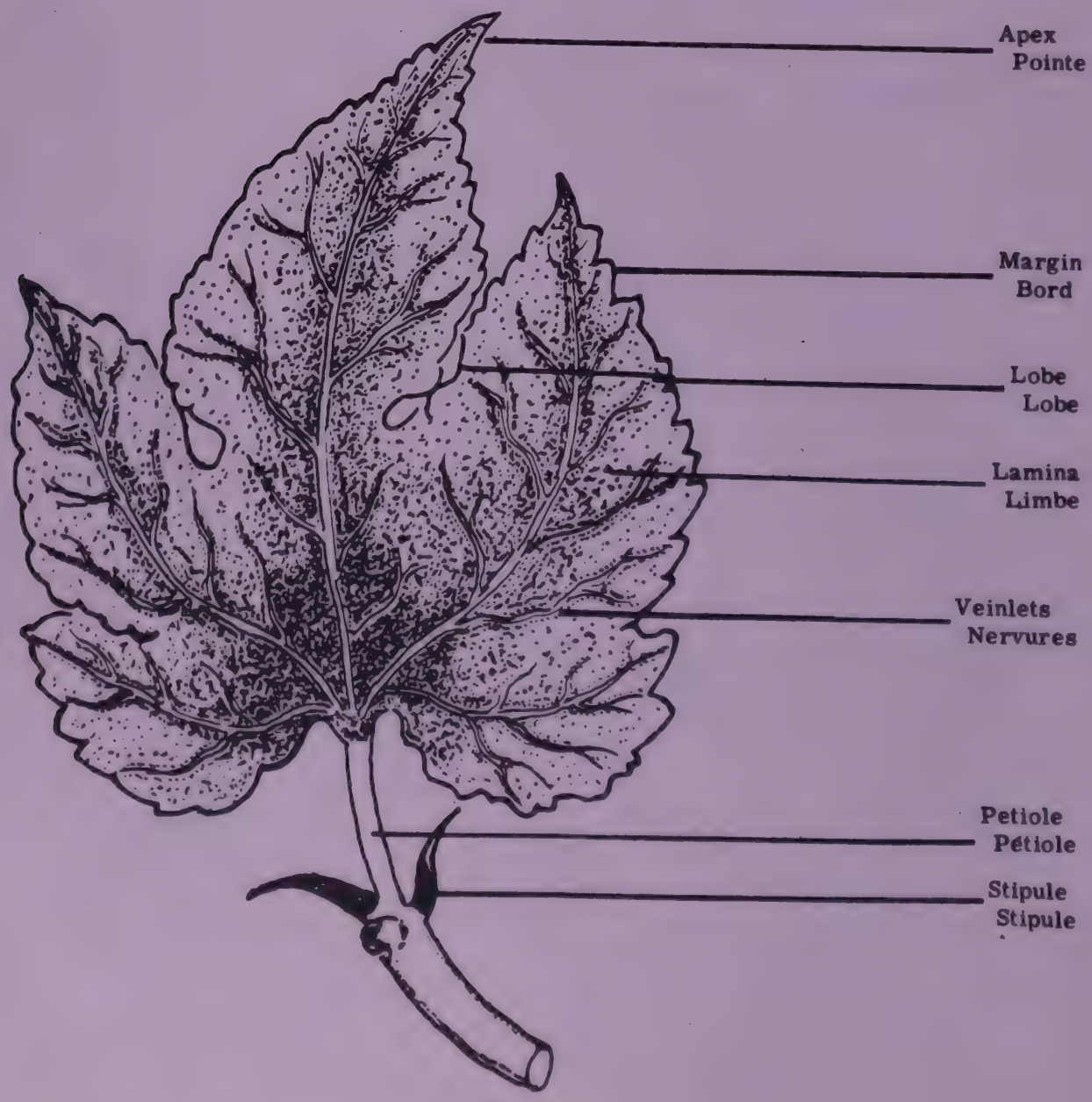

Apex
Pointe
Margin
Bord
Lobe
Lobe
Lamina
Limbe
Veinlets
Nervures
Petiole
Pétiole
Stipule
Stipule

Fig. 8

Fig. 9

Fig. 10

Fig. 11

Fig. 12

Fig. 13

Fig. 17a

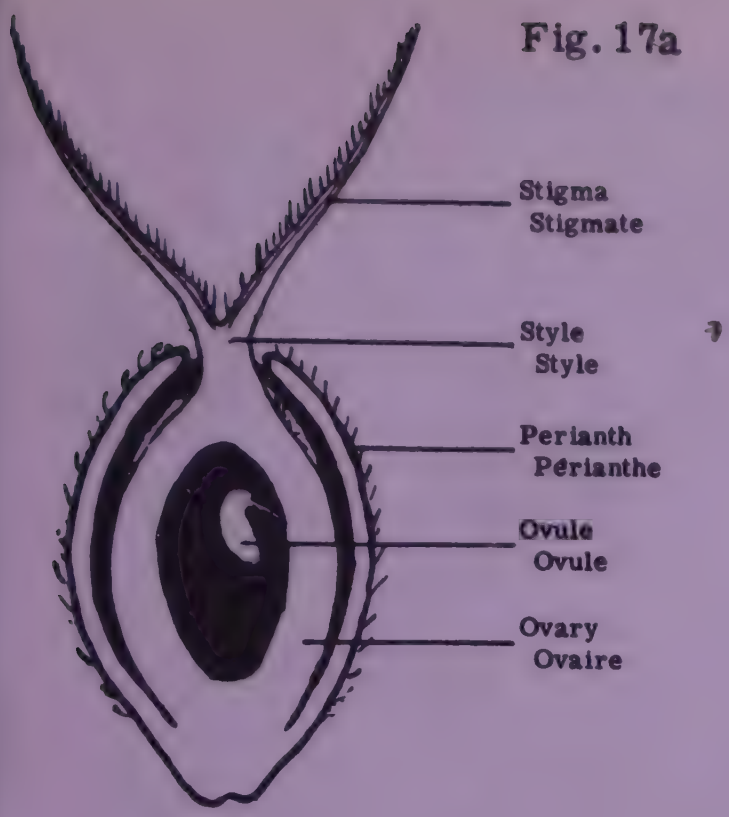


Fig. 17b

Fig. 16

Fig. 14

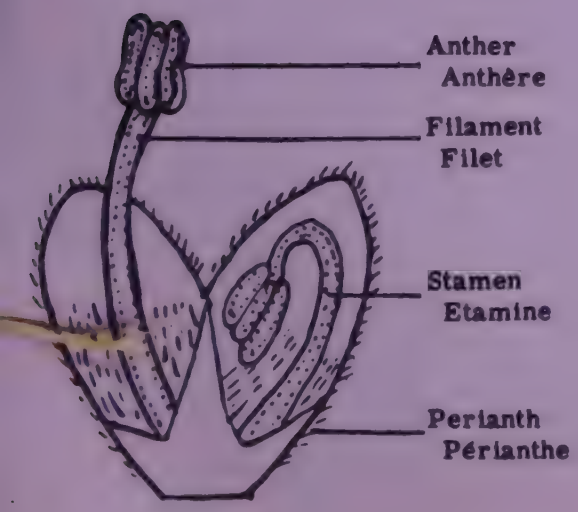
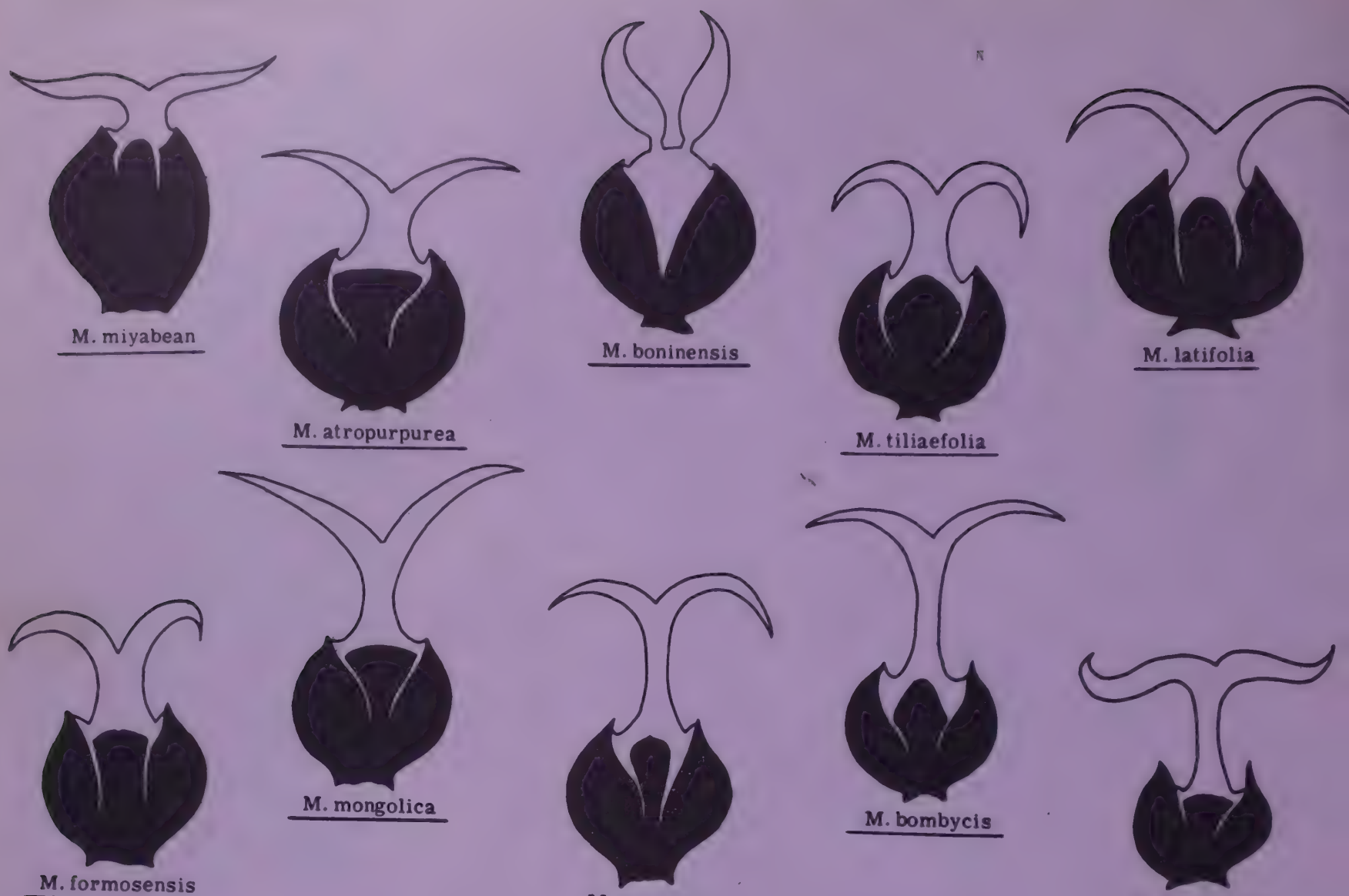


Fig. 15

Fig. 18



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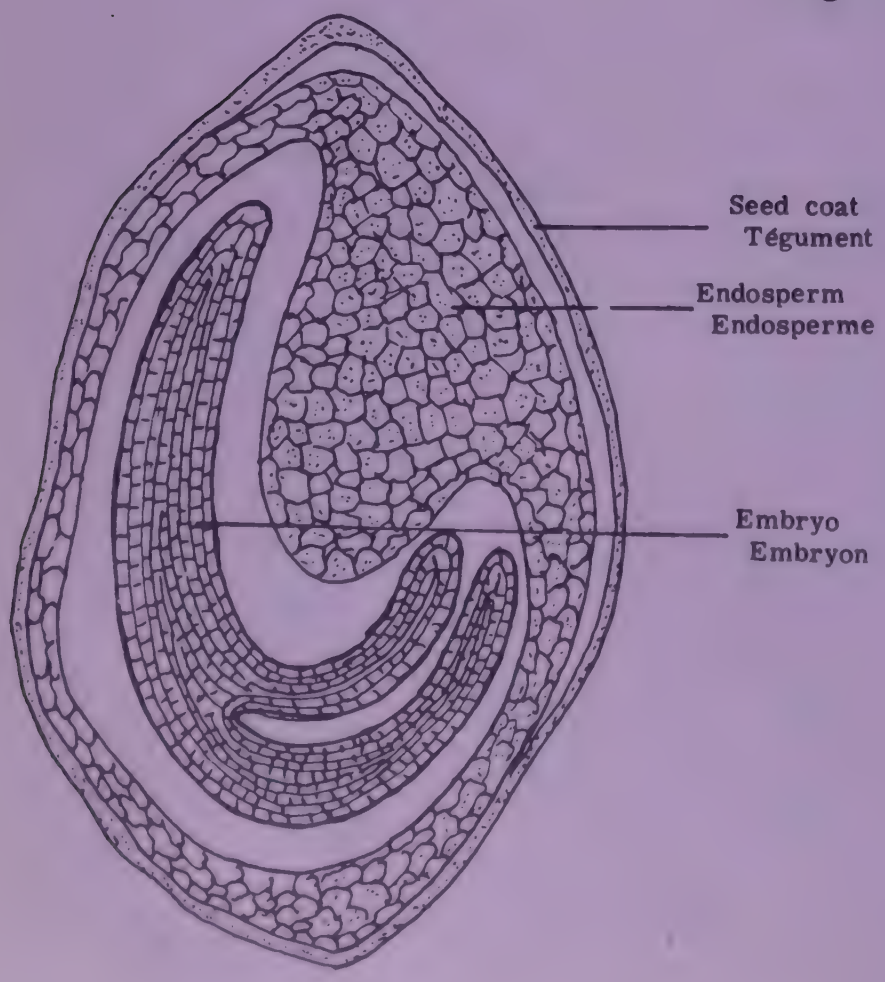


Fig. 21

Fig. 20a

Fig. 20b

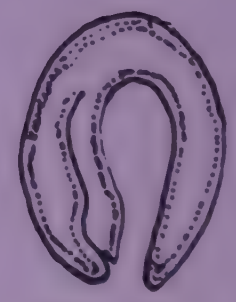


Fig. 22a

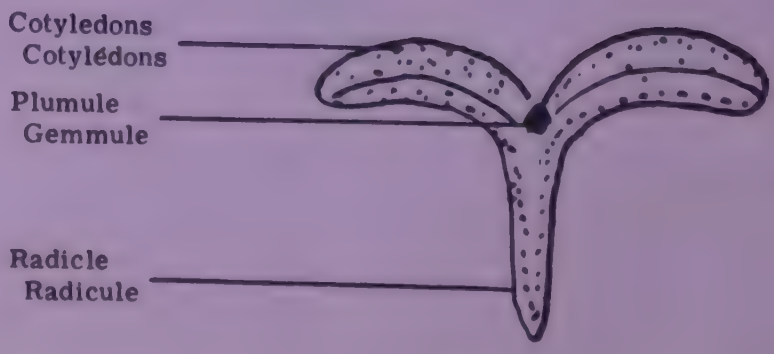
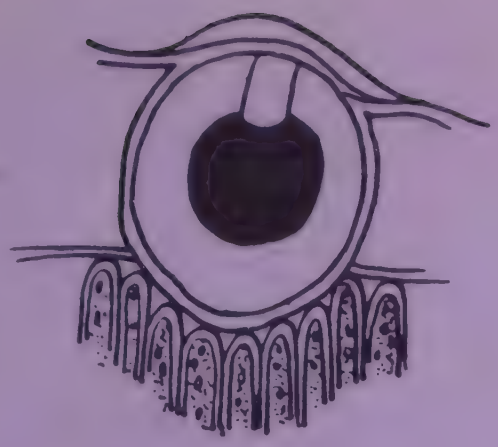


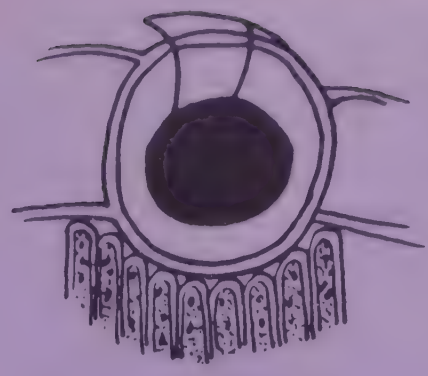
Fig. 22b

A TYPE
TYPE A

No projection
Pas de projection

3-10 μ
M. kagayama





B TYPE
TYPE B

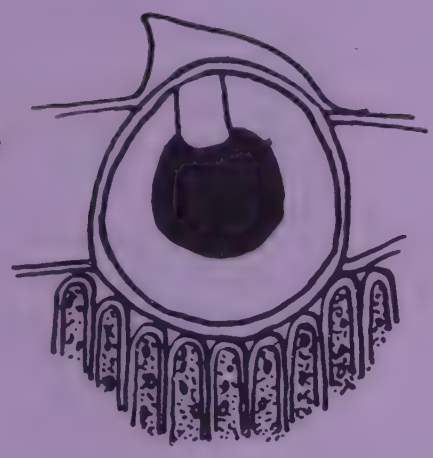
Small projection
Légère projection

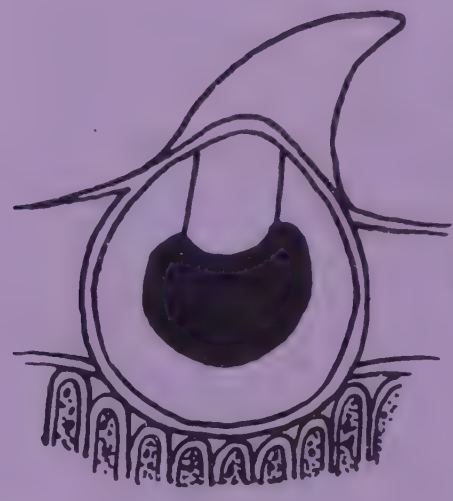
3-12 μ
M. multicaulis

C TYPE
TYPE C

Medium projection
Projection moyenne

18-32 μ
M. bombycis





D TYPE
TYPE D

Large projection
Forte projection

40-80 μ
M. laevigata

Fig. 23a

Fig. 23b

Fig. 23c (1)

Fig. 23c (2)

Fig. 23c (3)

Fig. 23c (4)

Fig. 23d (1)

Fig. 23d (2)

Fig. 23d (3)

Fig. 23d (4)

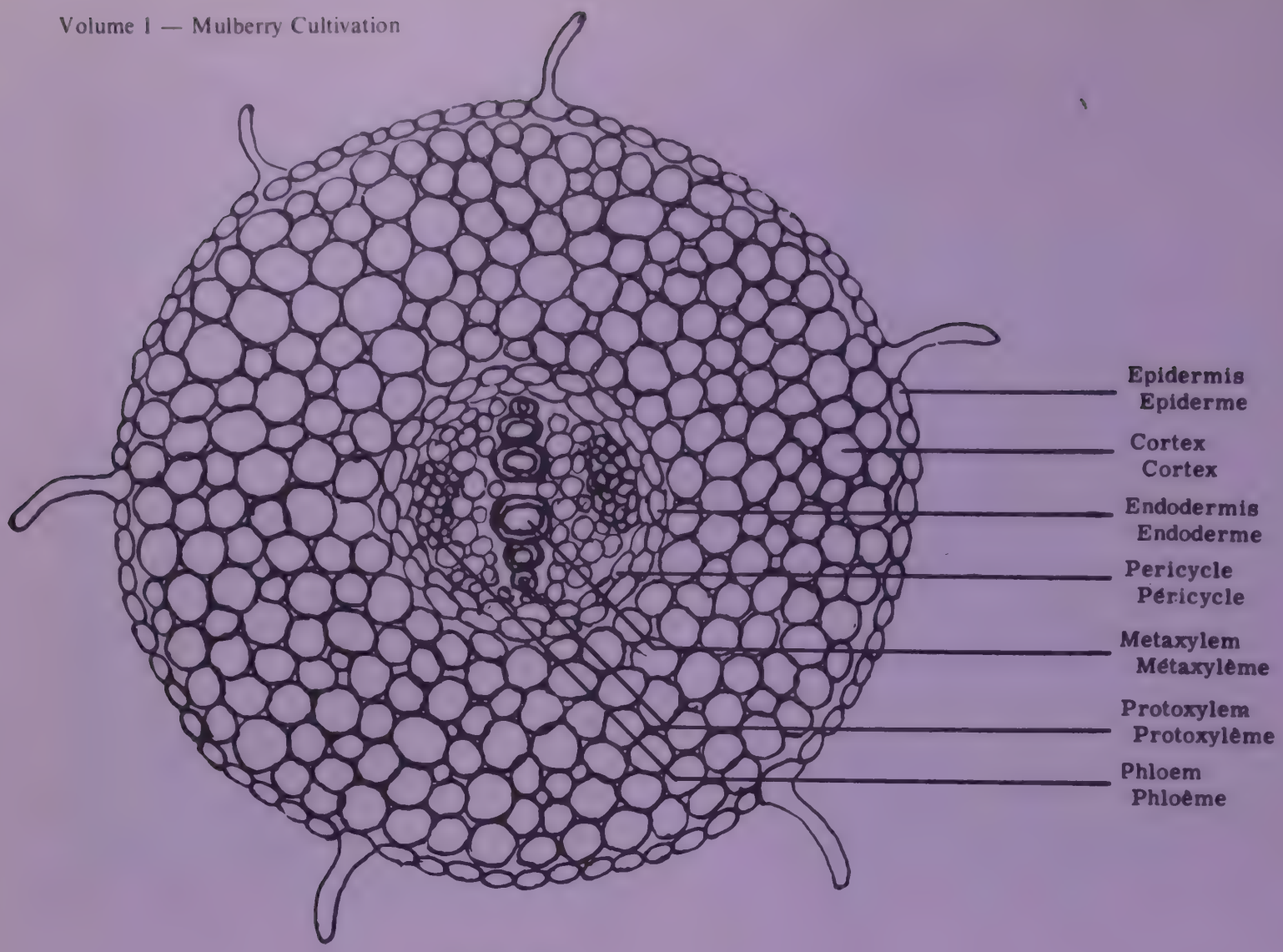


Fig. 24

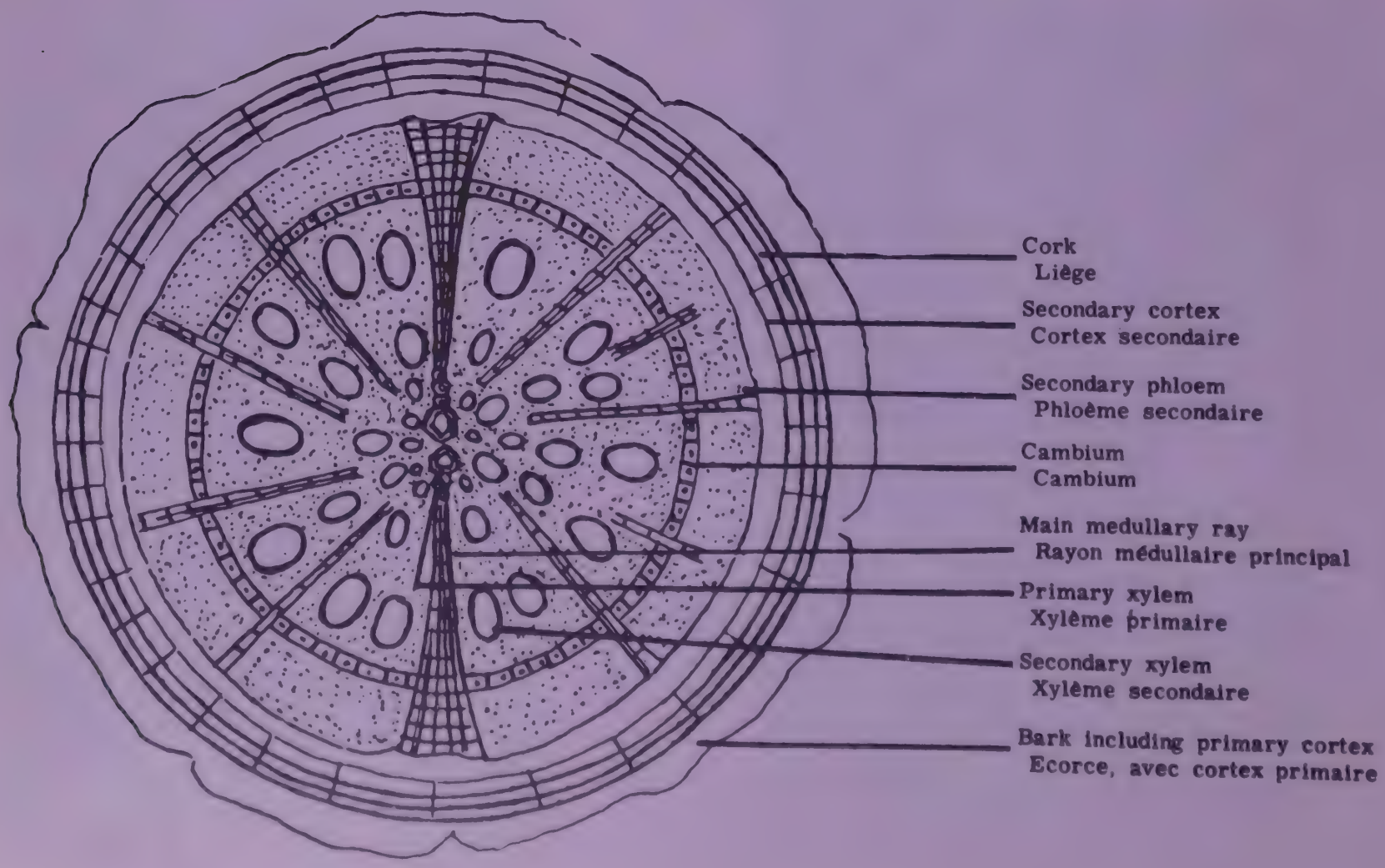
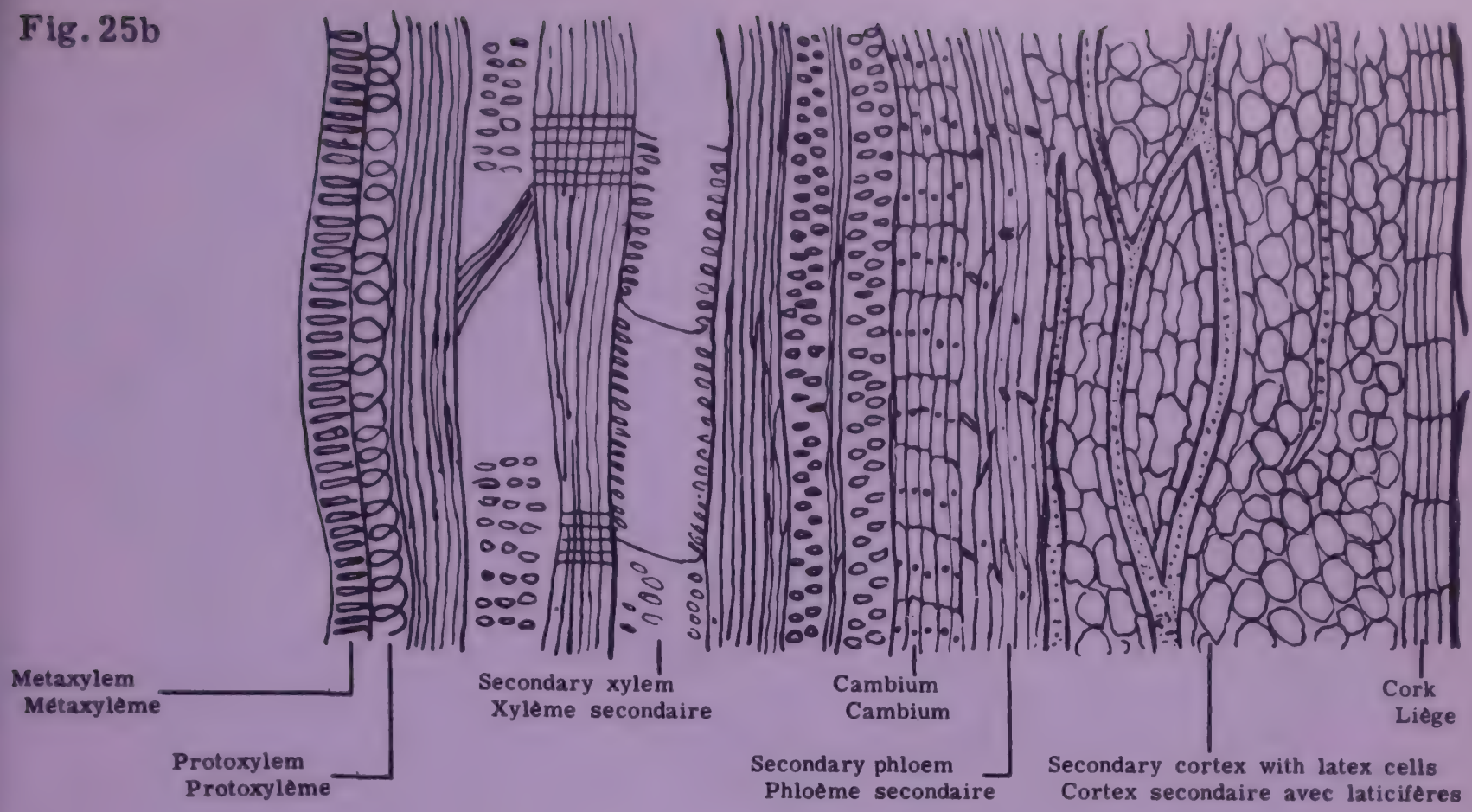


Fig. 25a

Fig. 25b



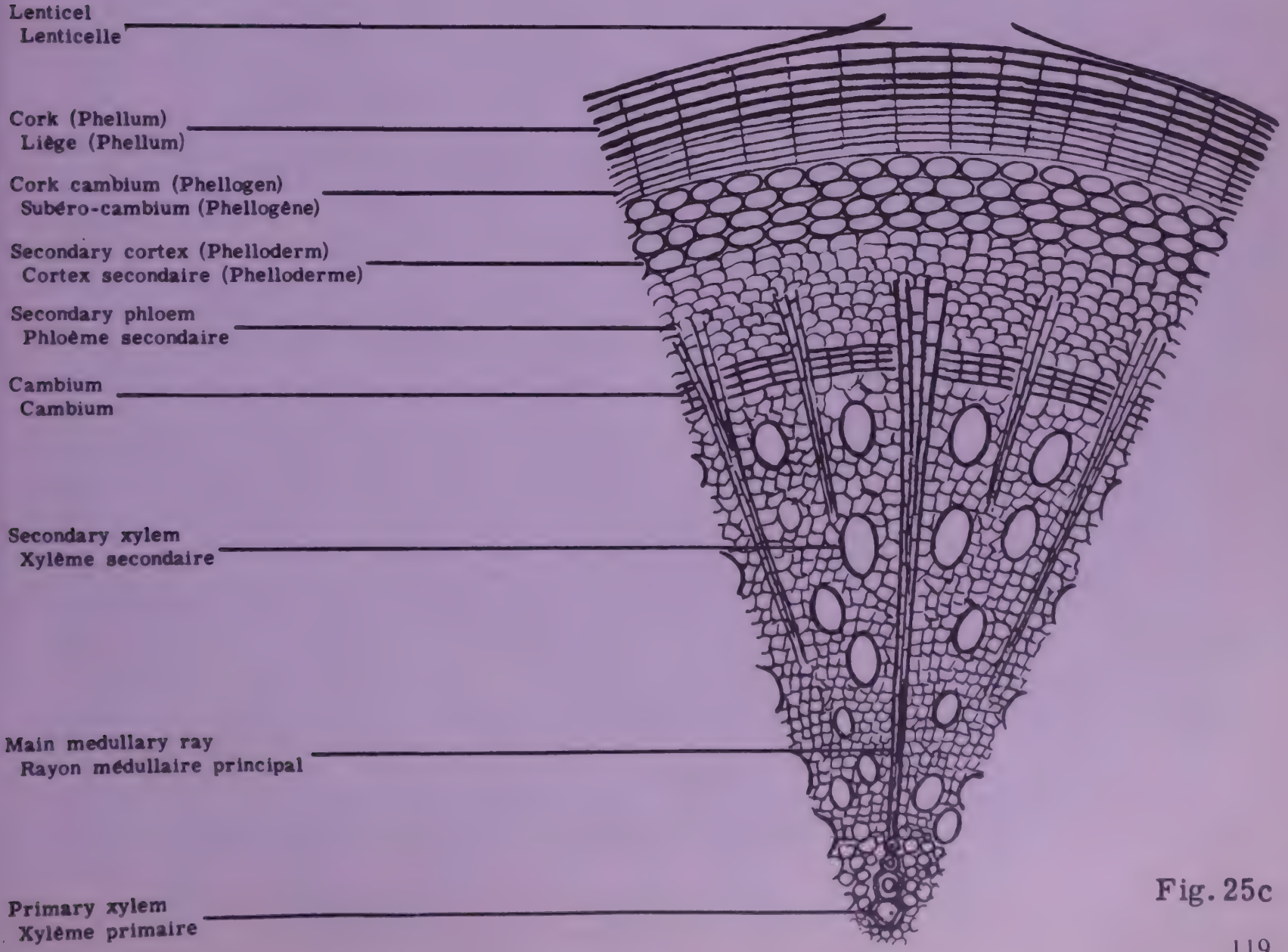


Fig. 25c

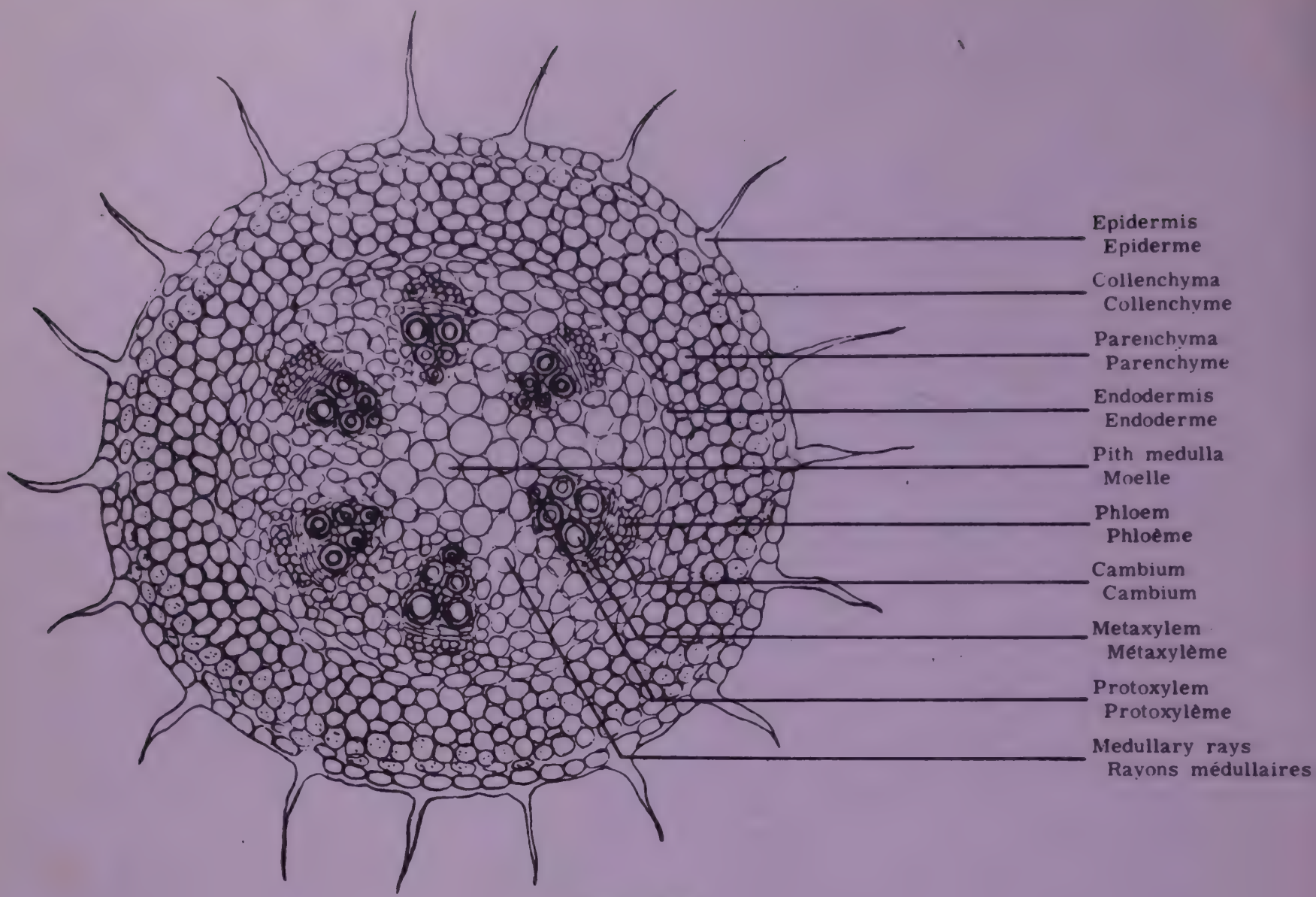

Epidermis
Epiderme
Collenchyma
Collenchyme
Parenchyma
Parenchyme
Endodermis
Endoderme
Pith medulla
Moelle
Phloem
Phloème
Cambium
Cambium
Metaxylem
Métaxylème
Protoxylem
Protoxylème
Medullary rays
Rayons médullaires

Fig. 26

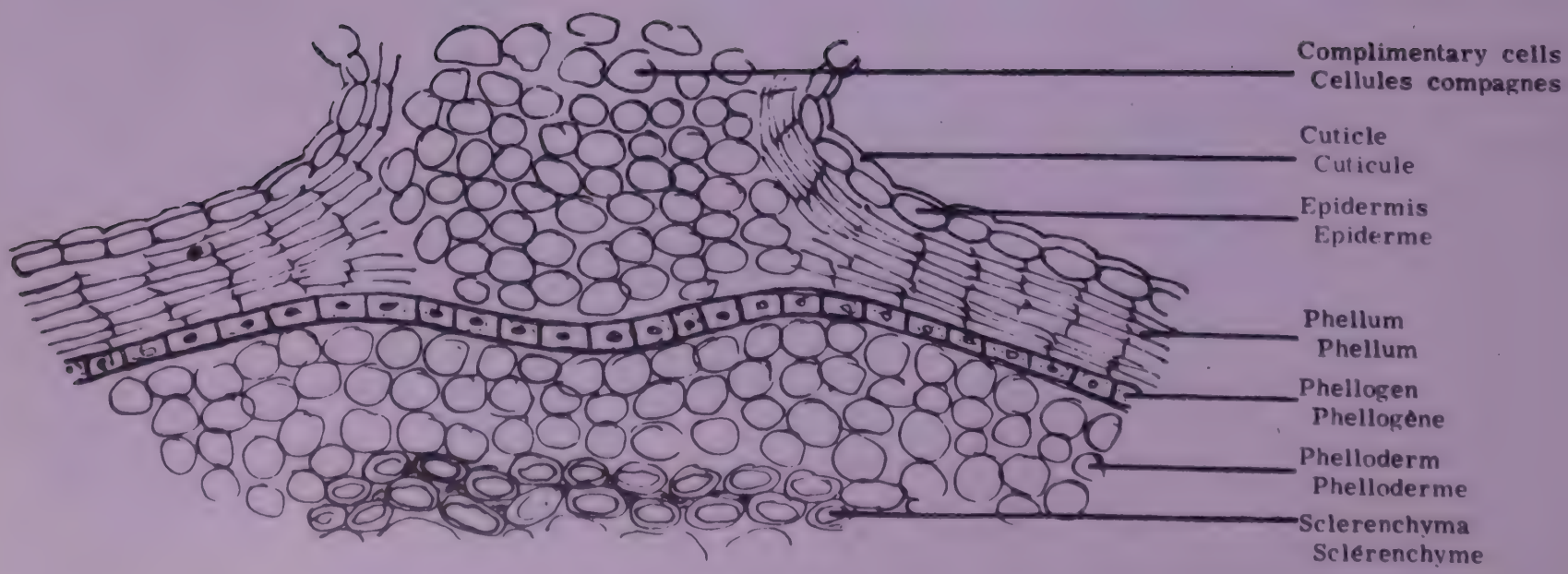

Complimentary cells
Cellules compagnes
Cuticle
Cuticule
Epidermis
Epiderme
Phellum
Phellum
Phellogen
Phellogène
Phelloderm
Phelloderme
Sclerenchyma
Sclérenchyme

Fig. 27

Fig. 28a

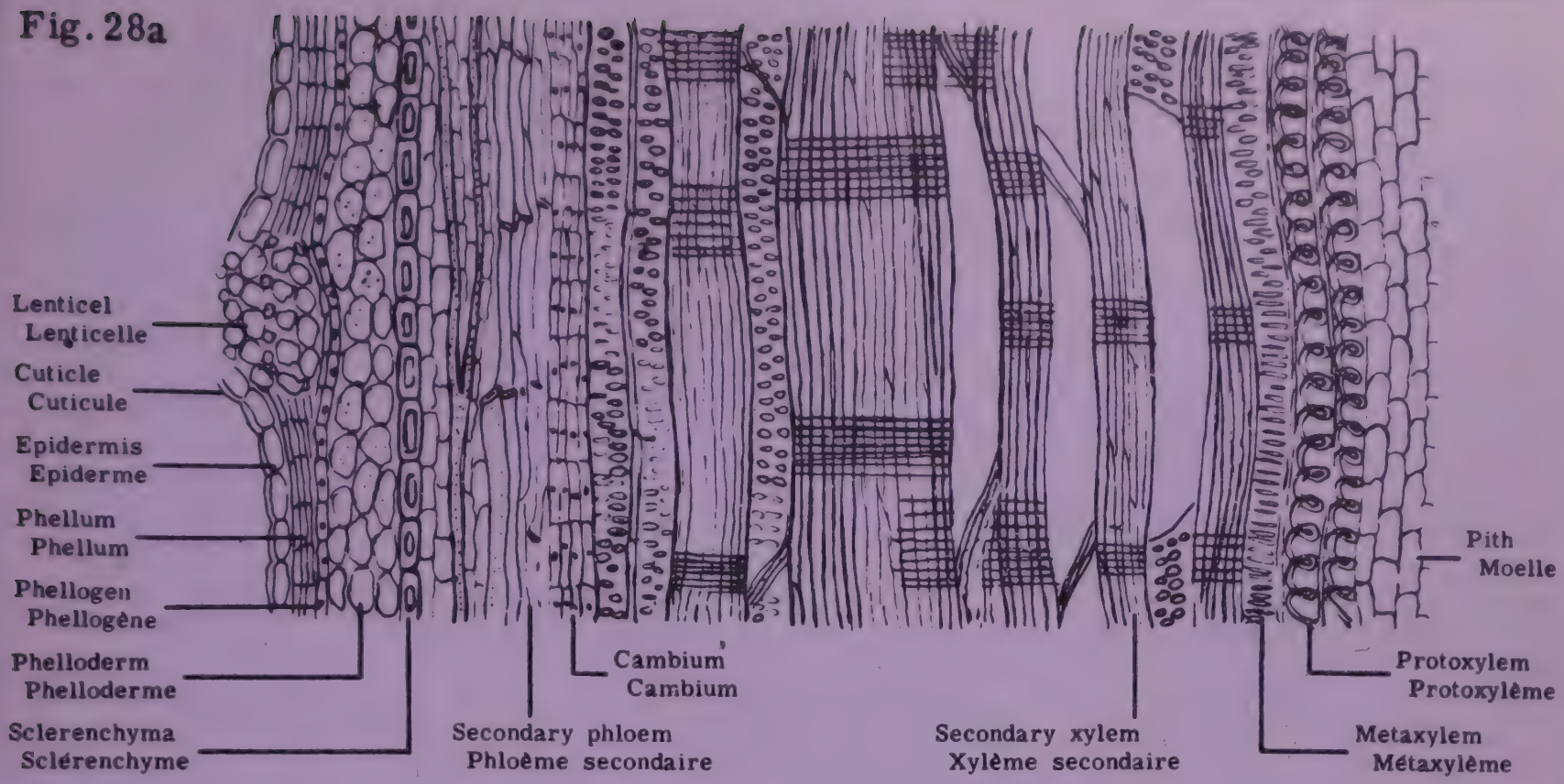


Fig. 28b

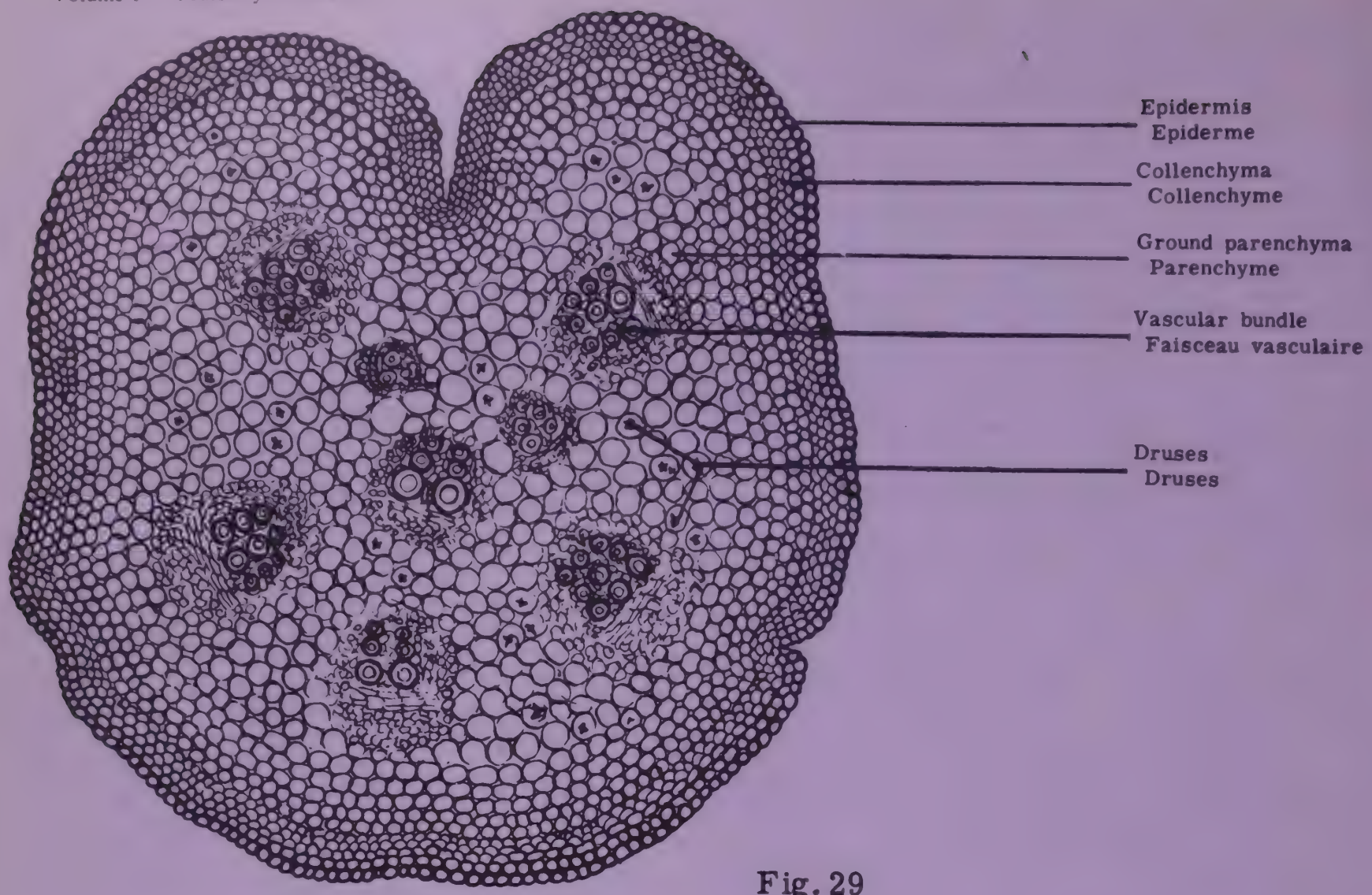


Fig. 29

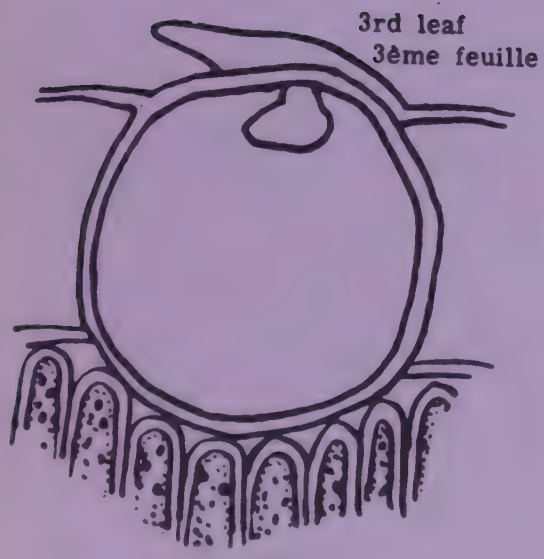


Fig. 30a

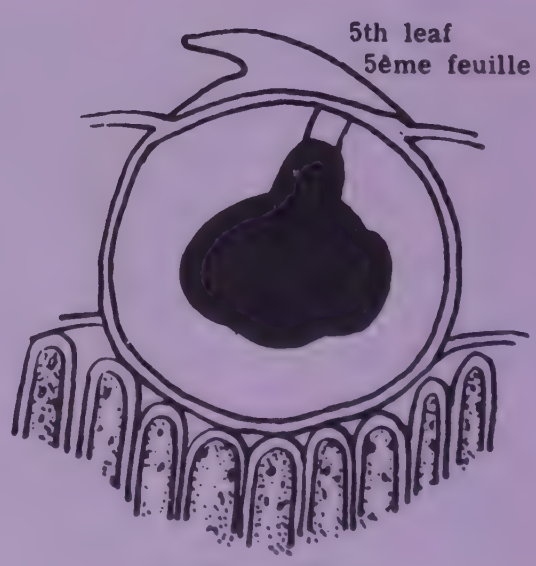


Fig. 30b

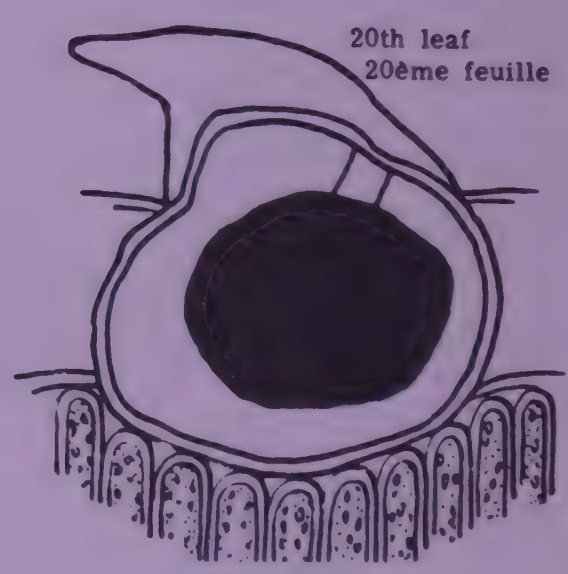
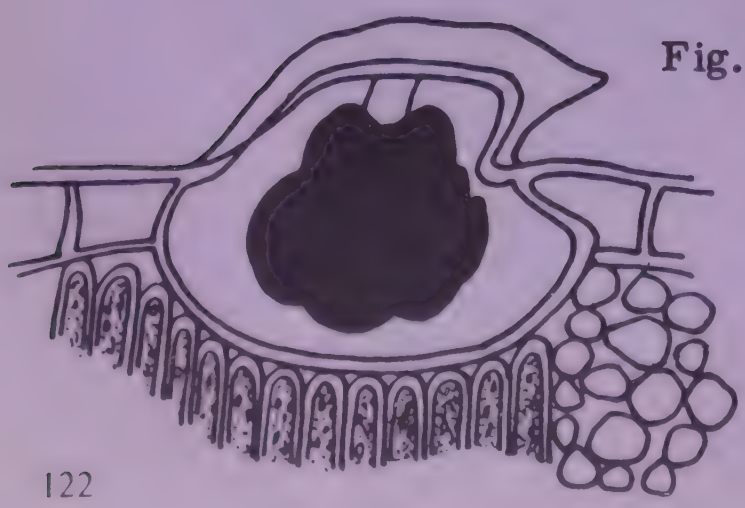


Fig. 30c



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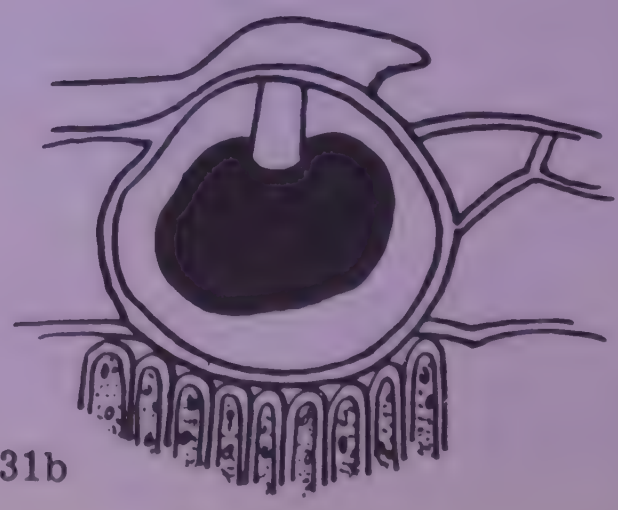


Fig. 31b

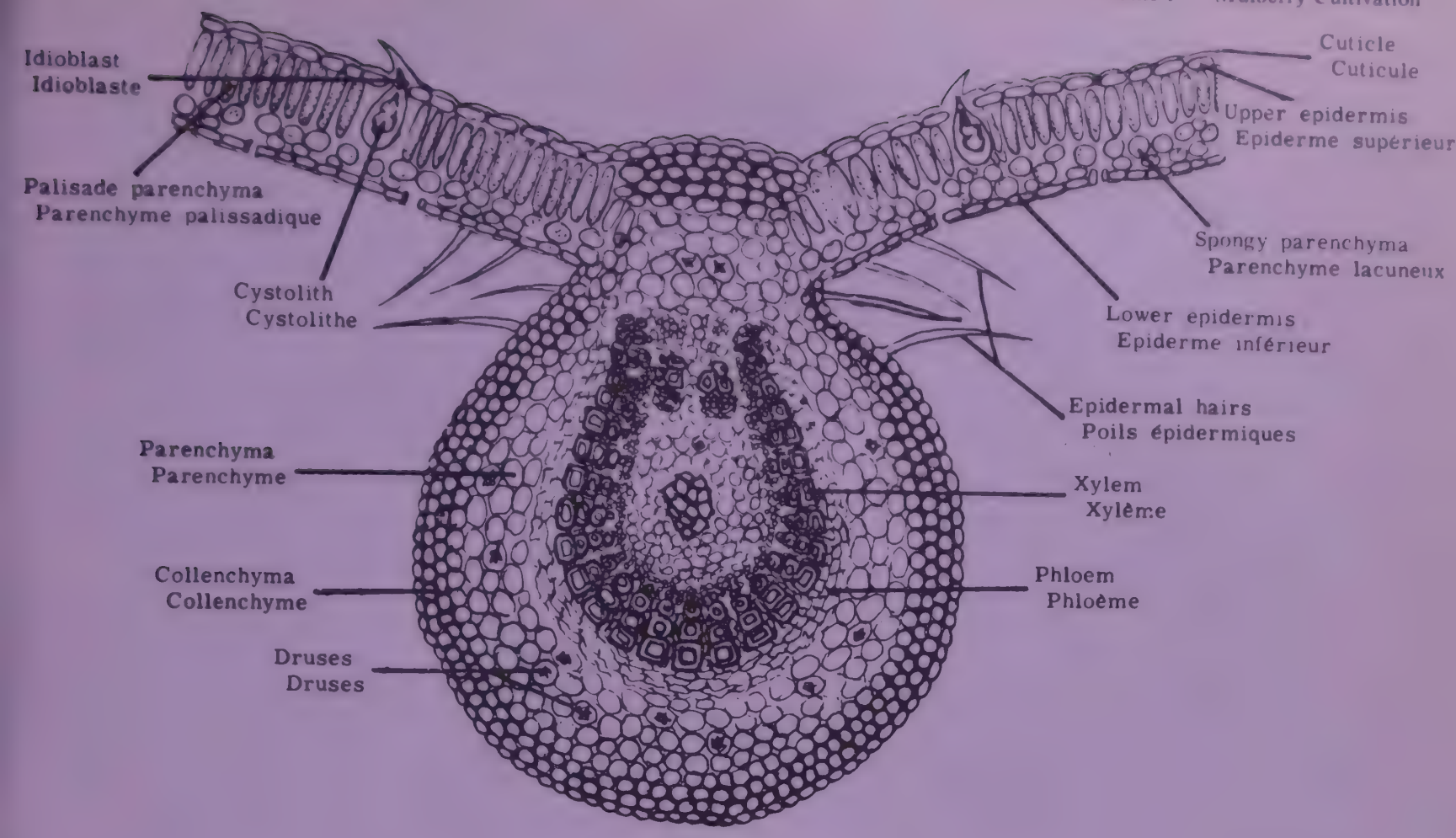


Fig. 32a

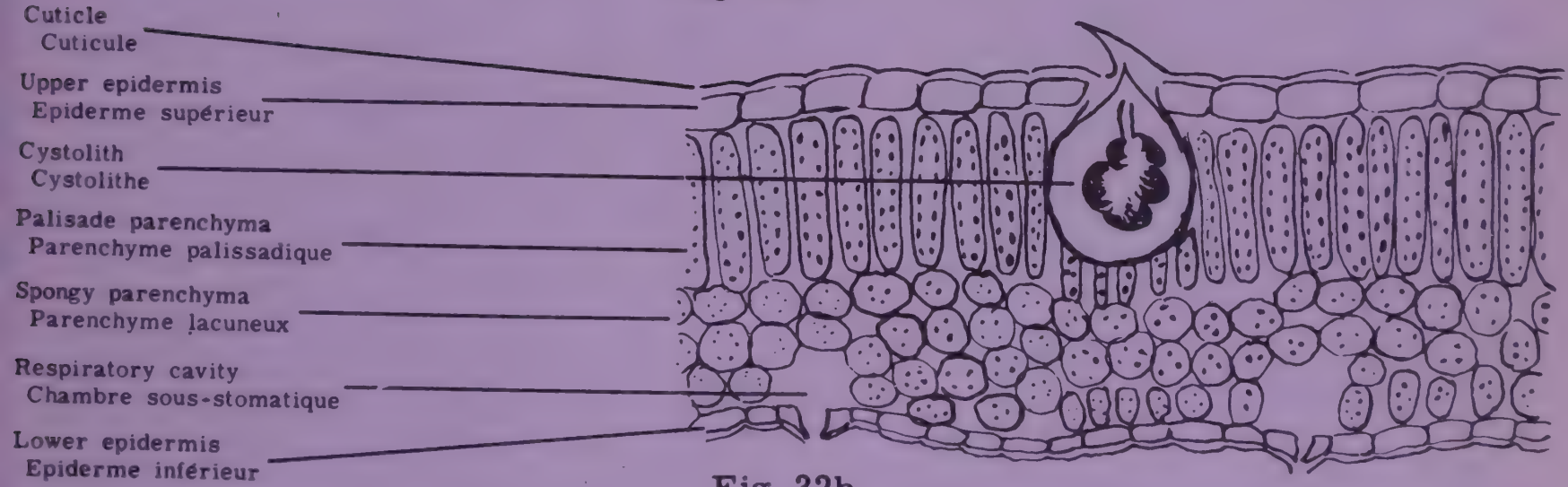


Fig. 32b

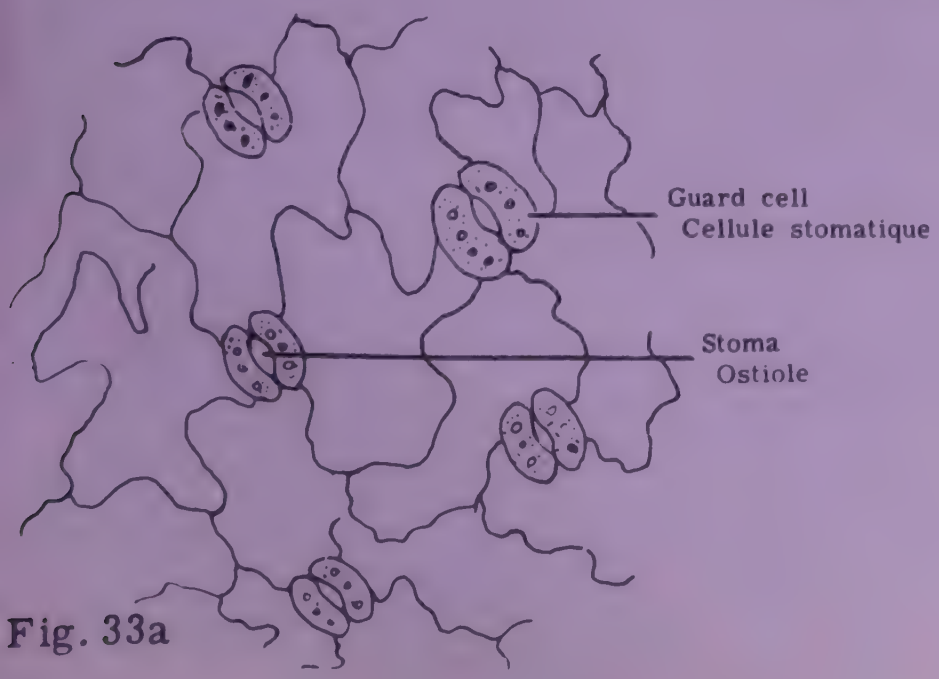


Fig. 33a

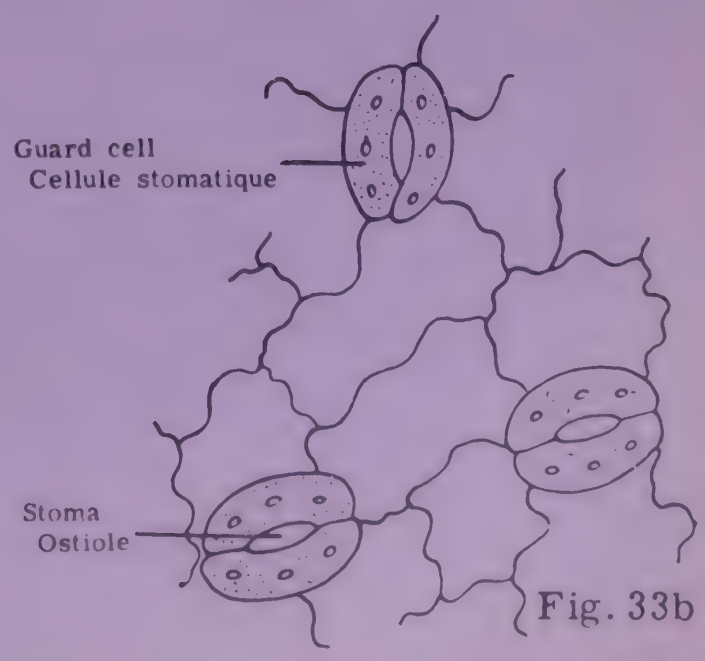


Fig. 33b

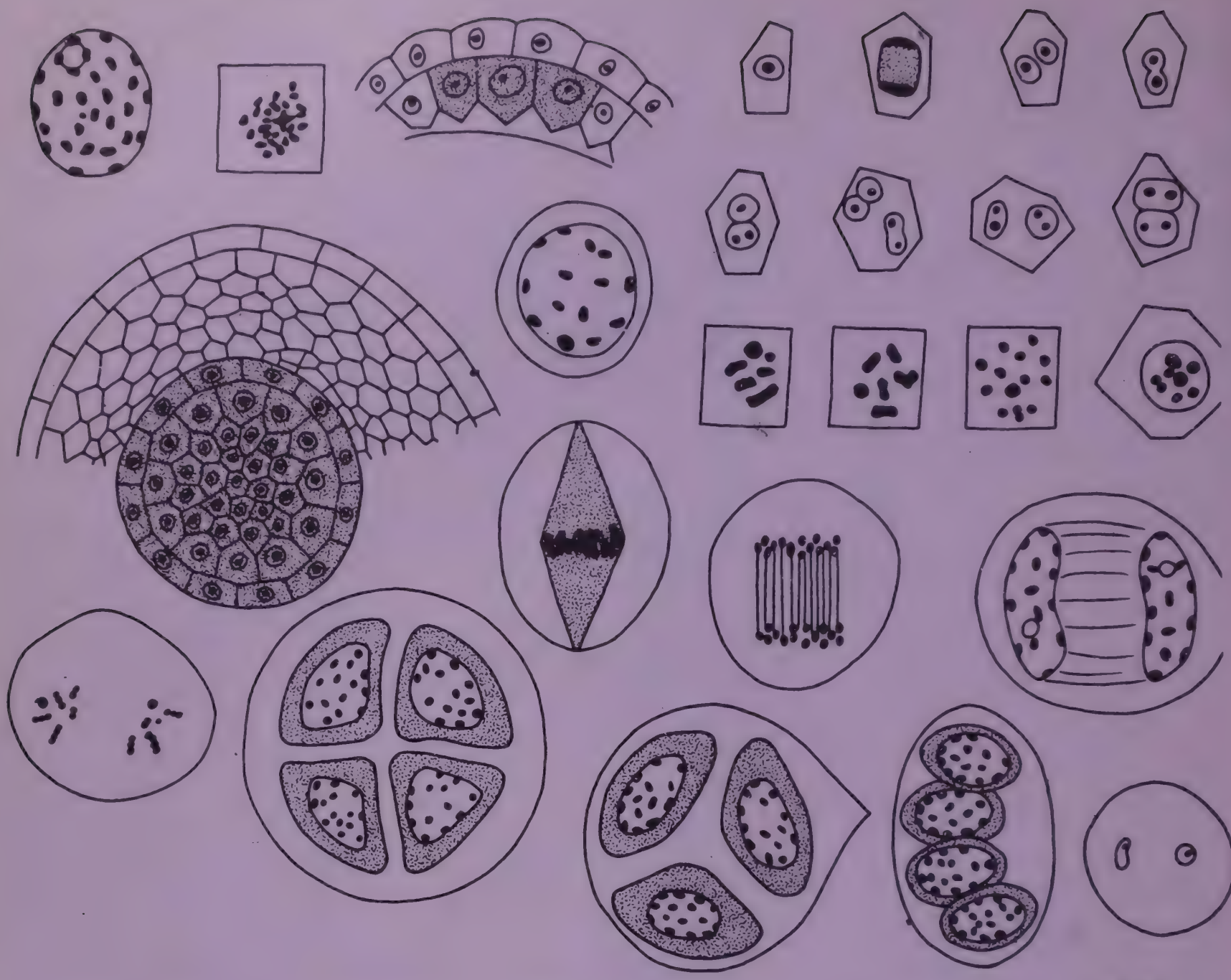
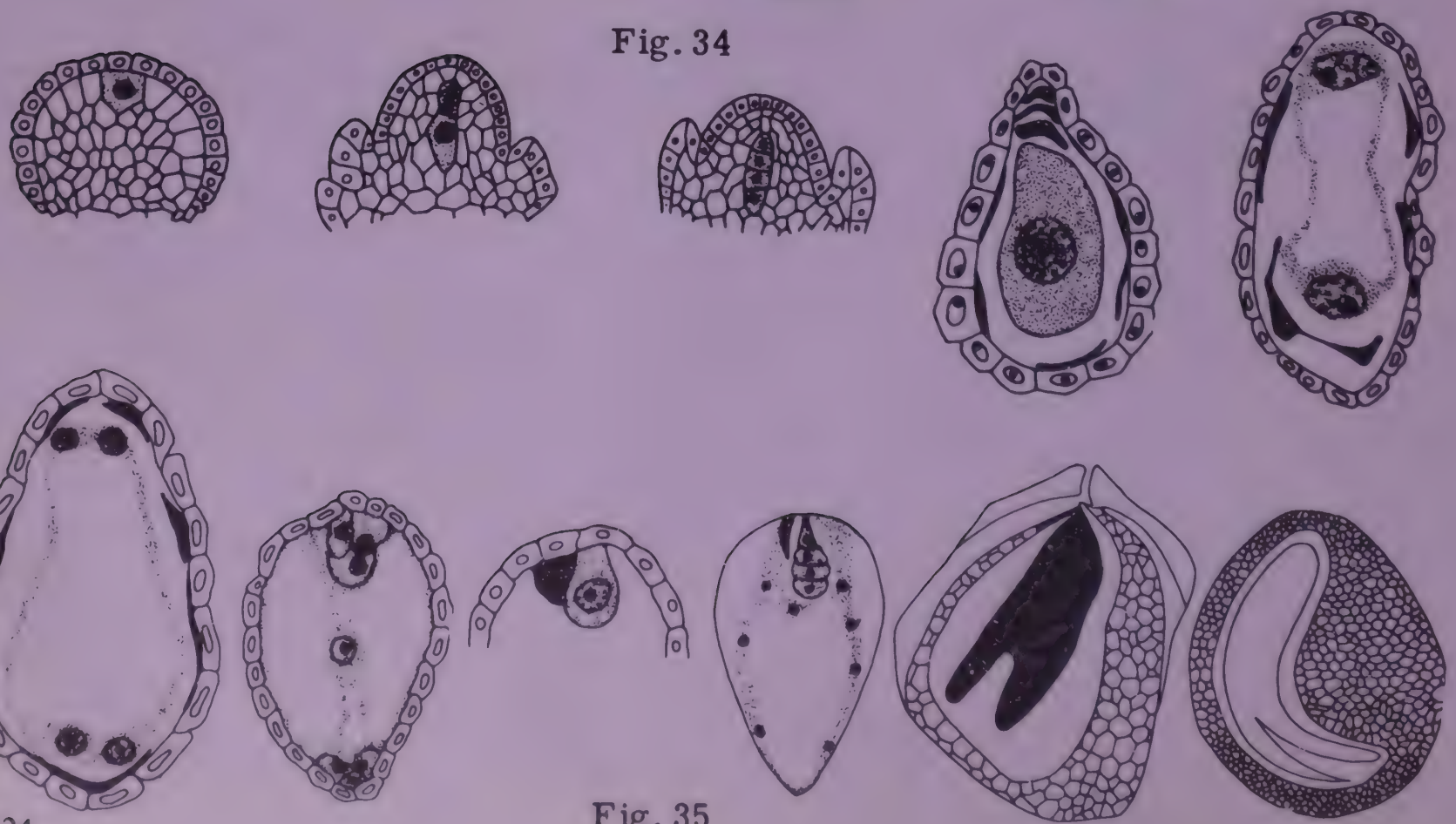


Fig. 34



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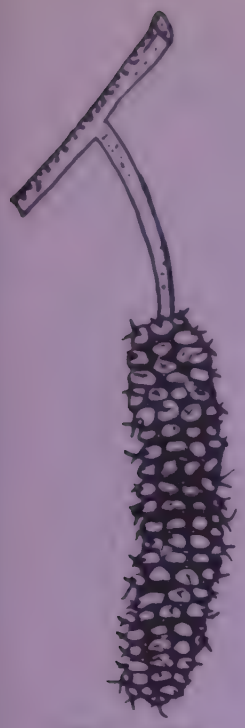


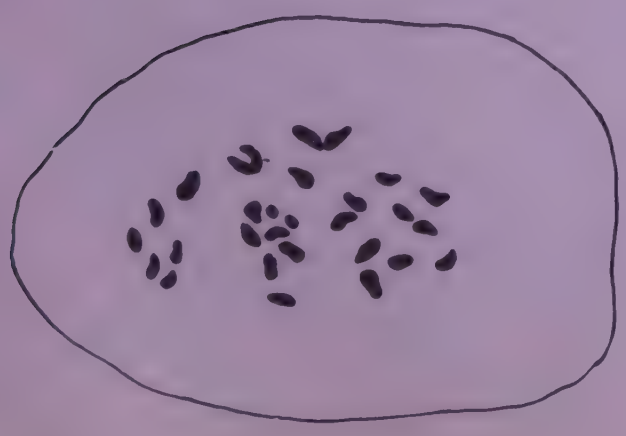
Fig. 36a

Fig. 36b

Fig. 37

Fig. 38a

Fig. 38b



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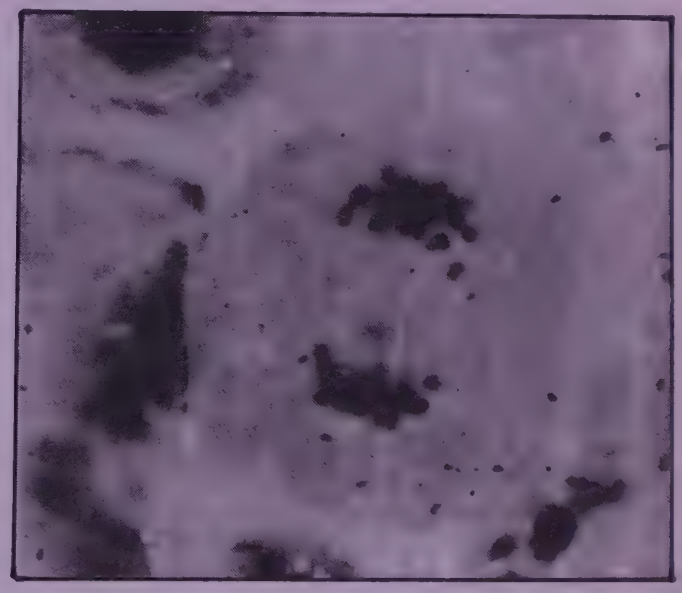


Fig. 38d

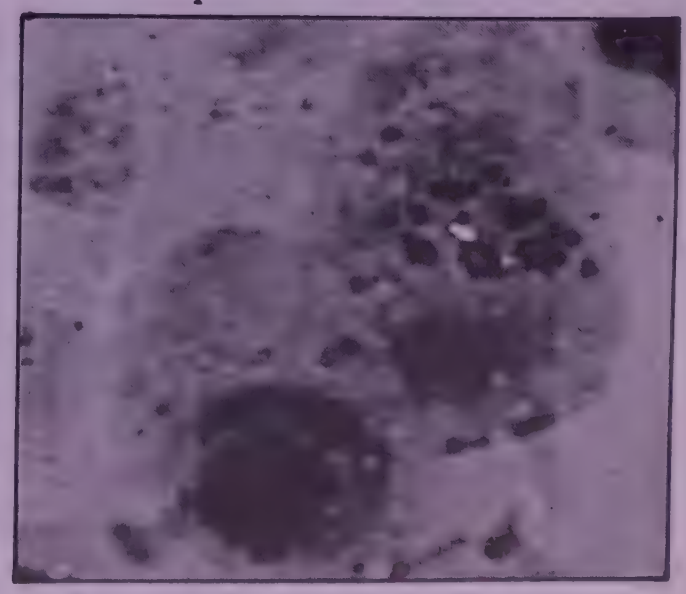


Fig: 38e

Fig.39

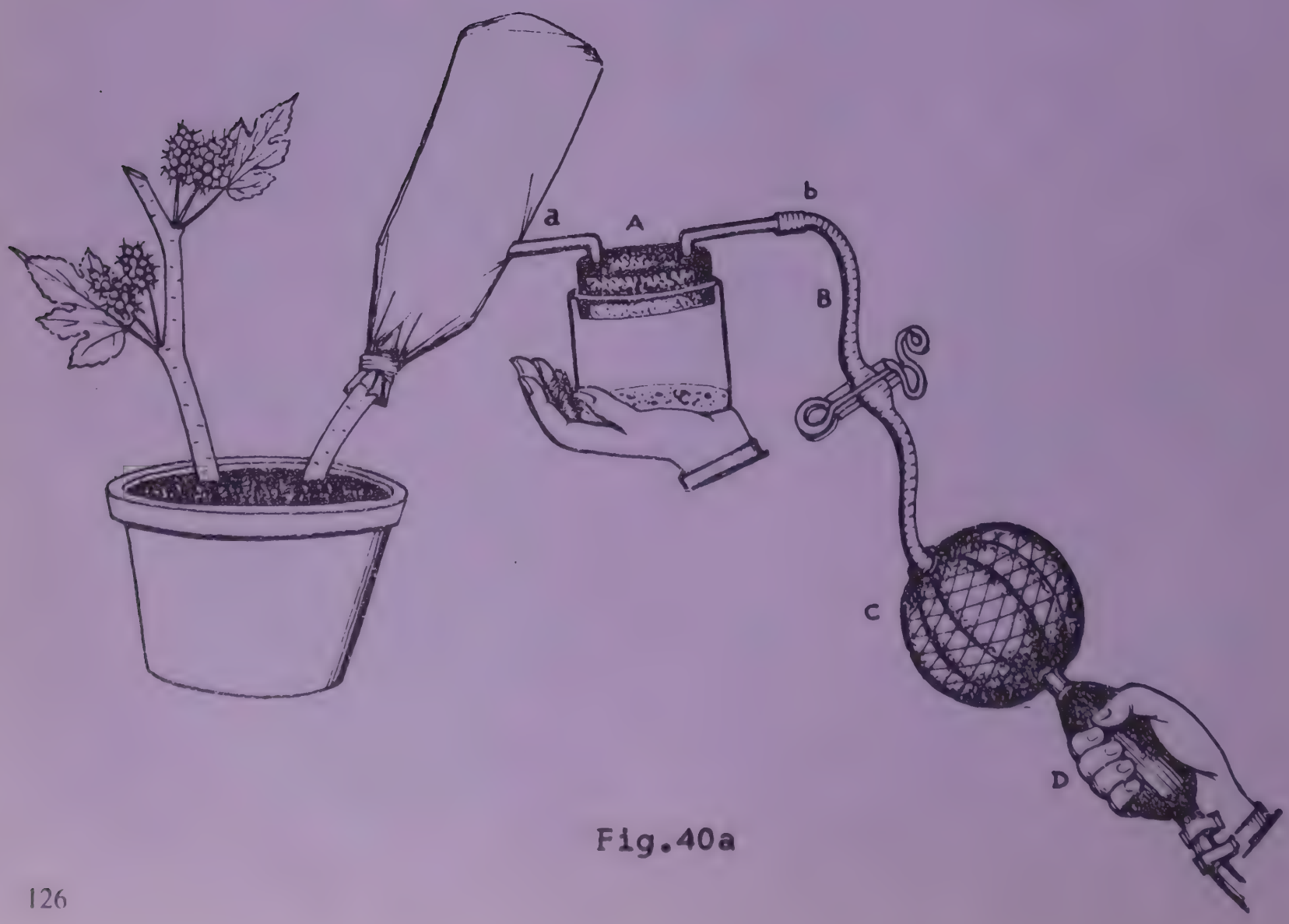


Fig.40a

Fig.41

Fig.40b

Fig.42

Fig. 43a

Fig. 43b

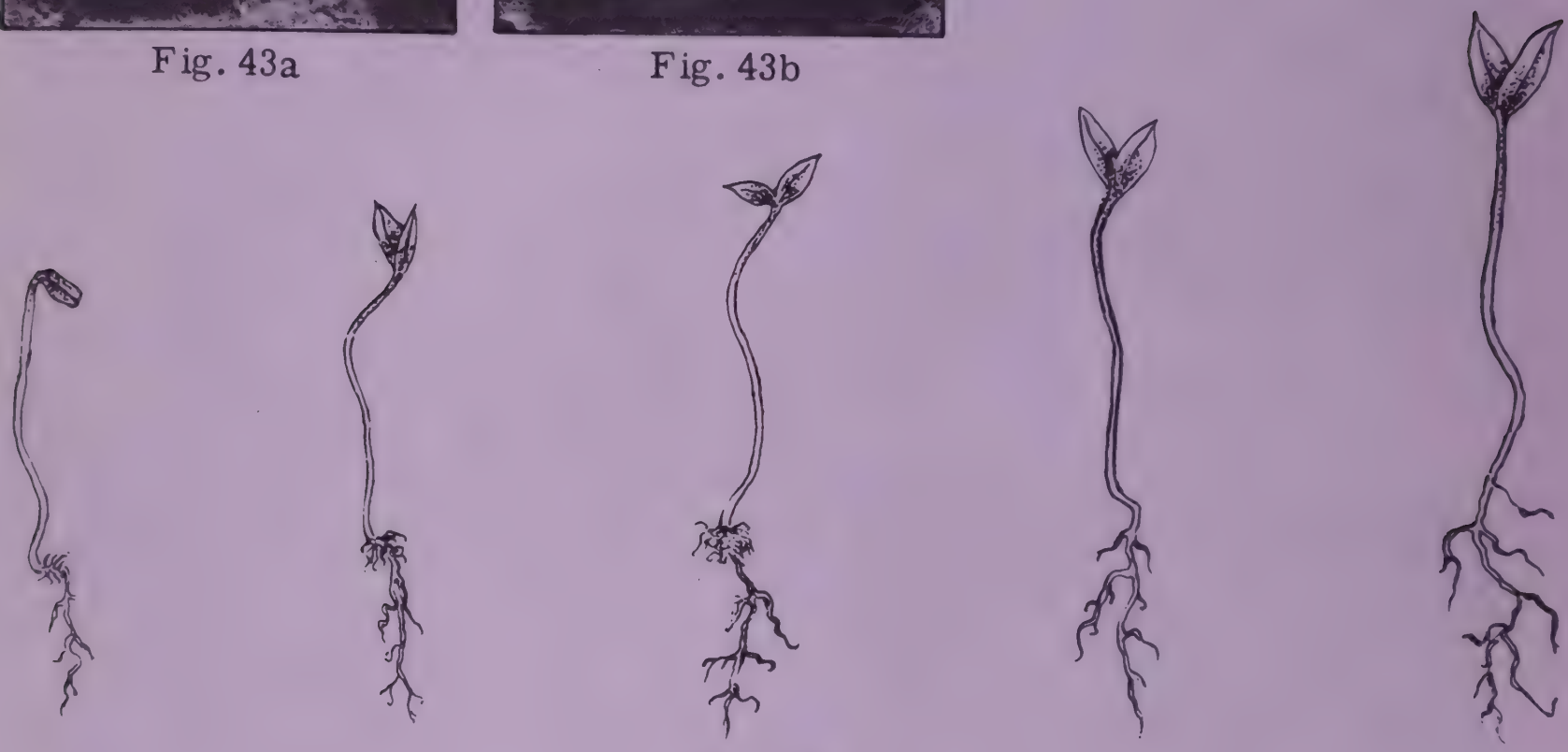


Fig. 45

Fig. 44

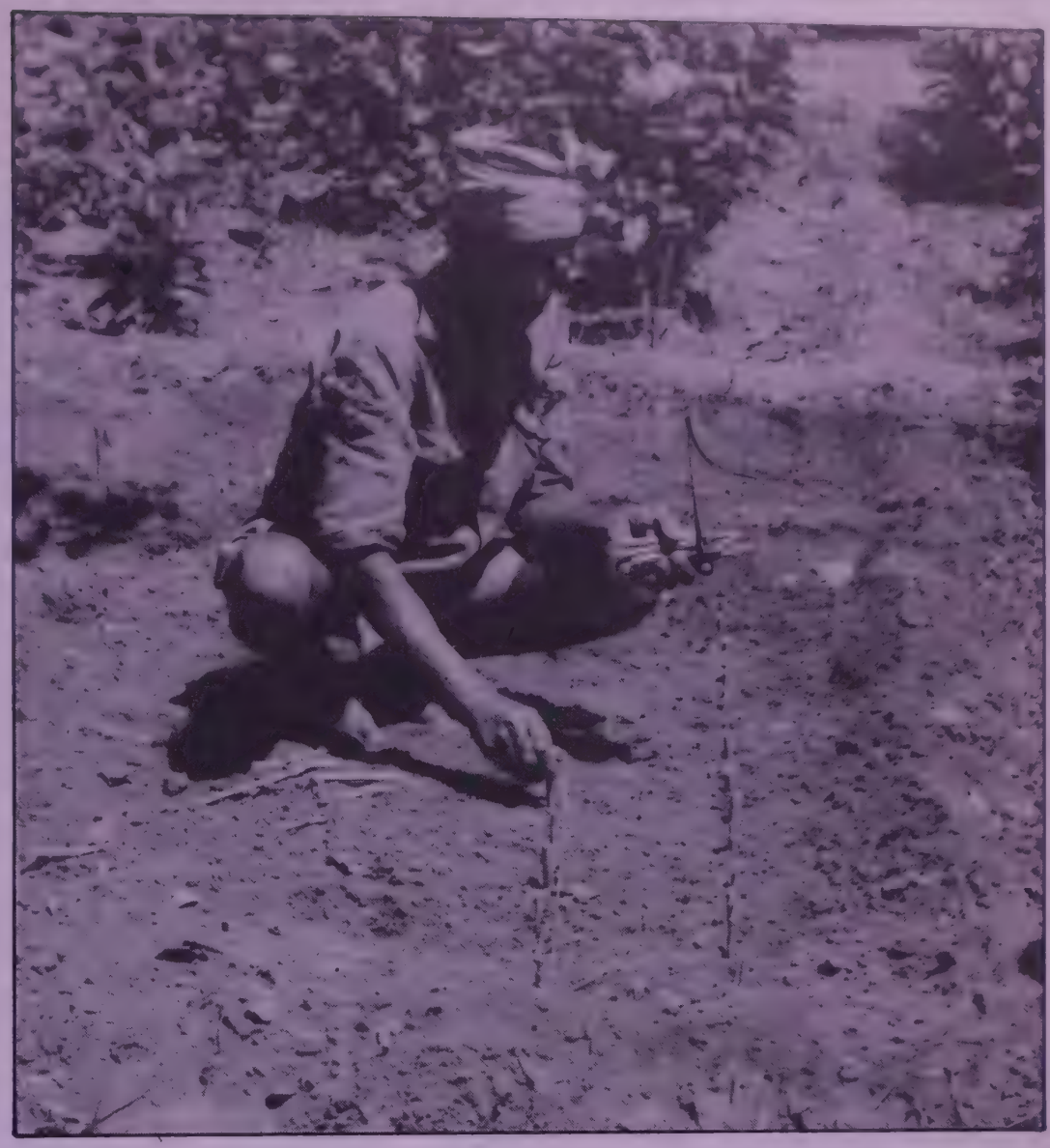
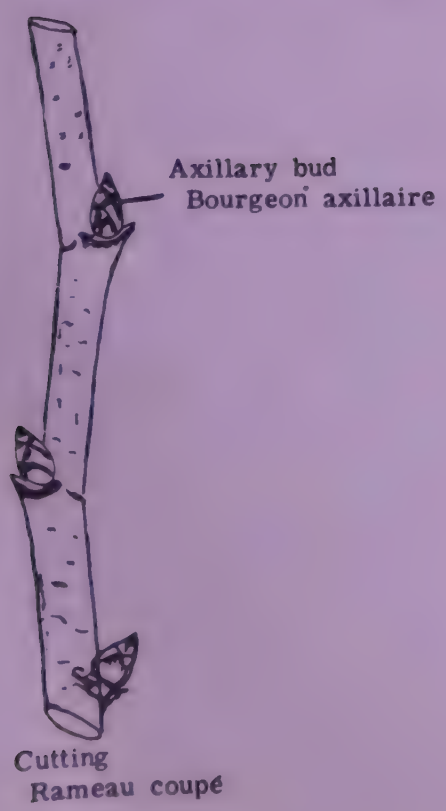
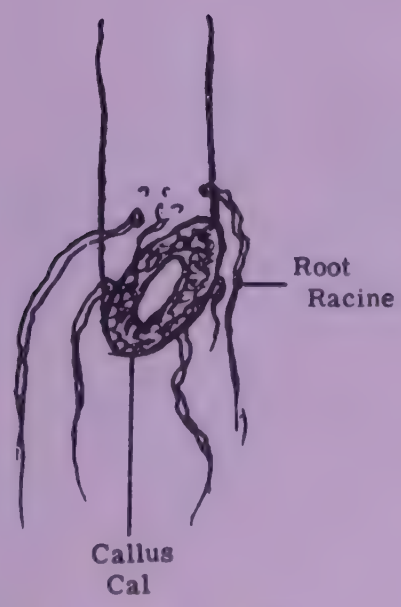


Fig. 46

Fig. 47





Formation of callus
at cut end
Formation d'un cal
à la surface de section

Fig. 48

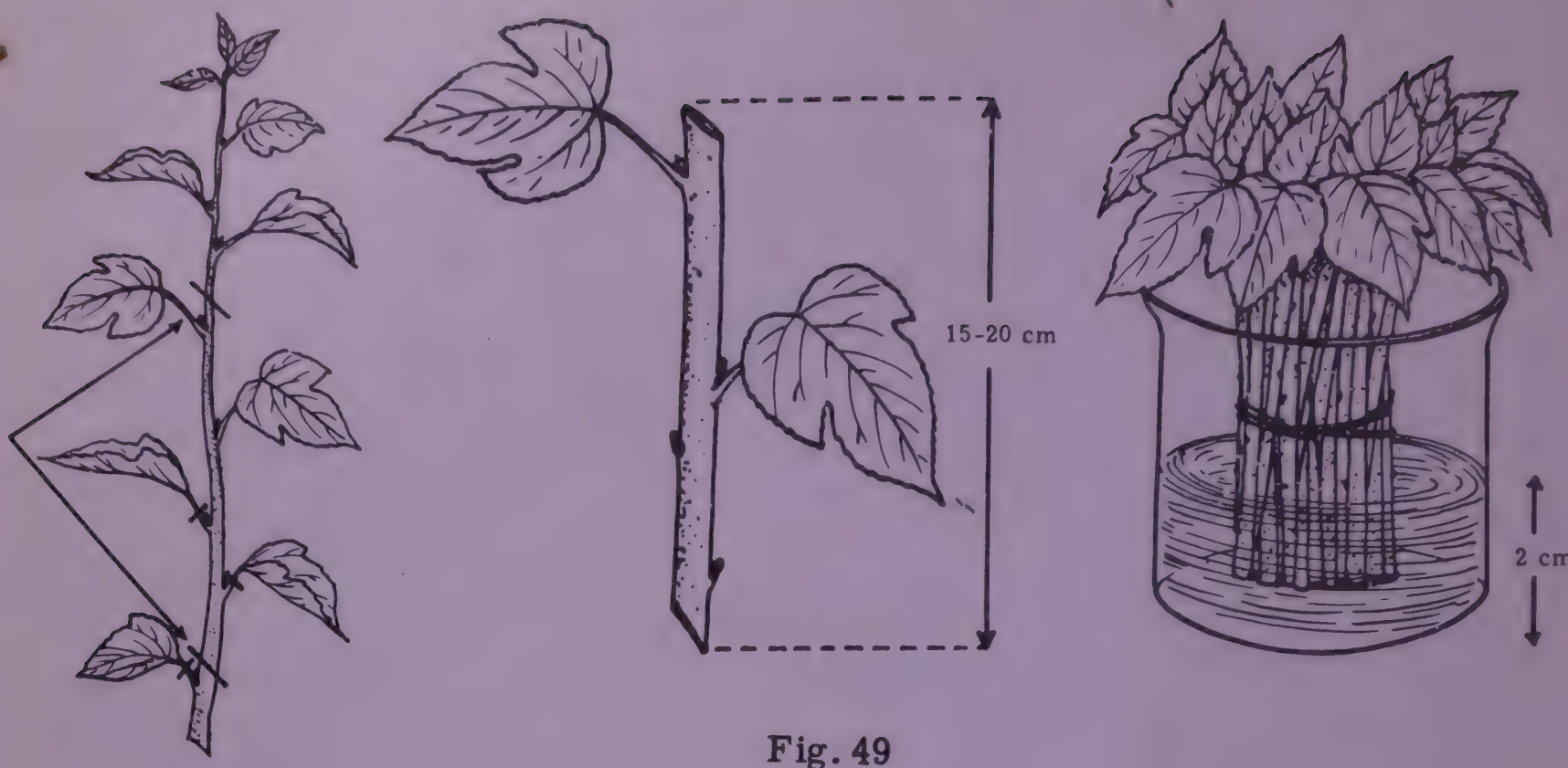


Fig. 49

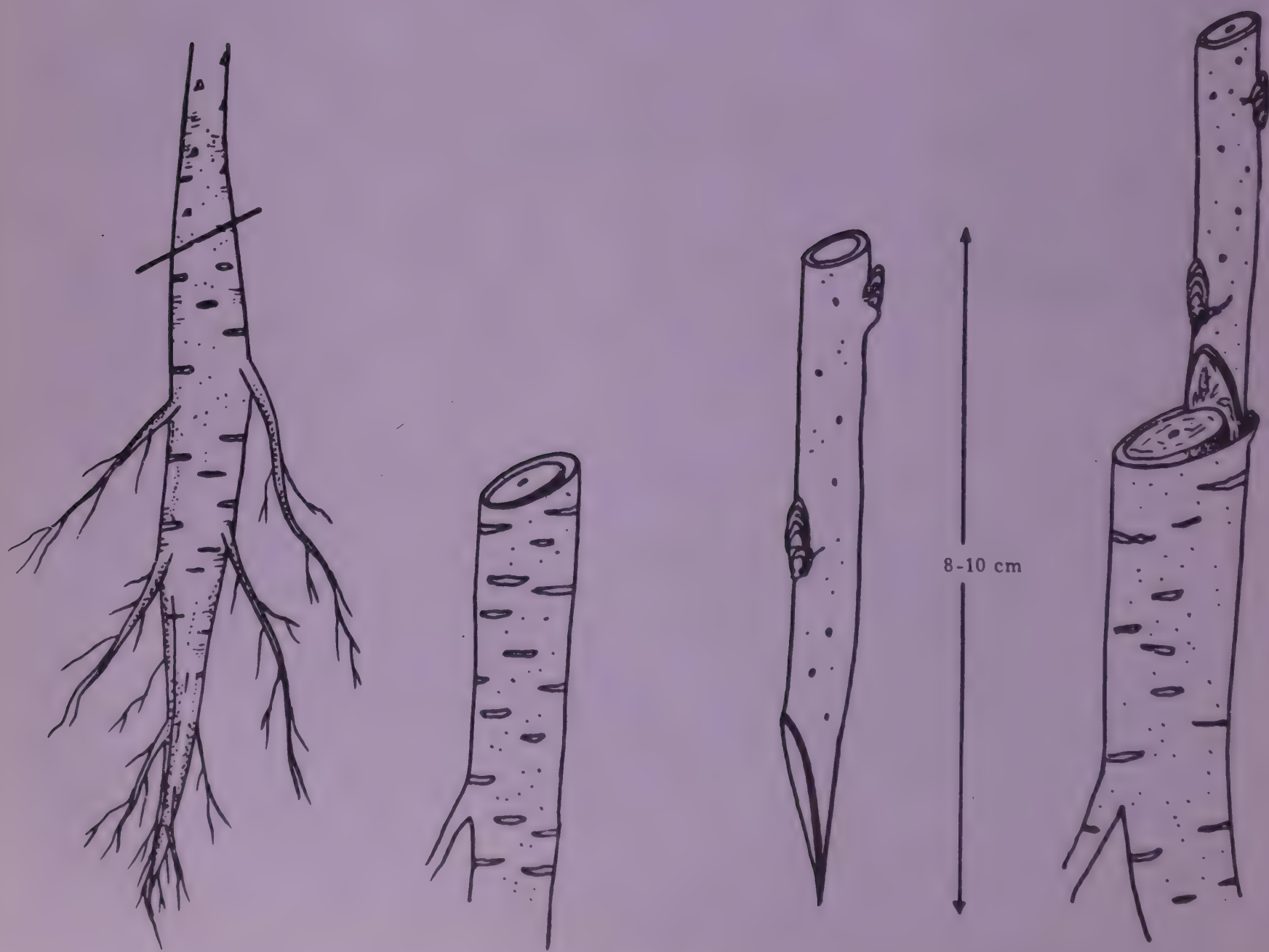
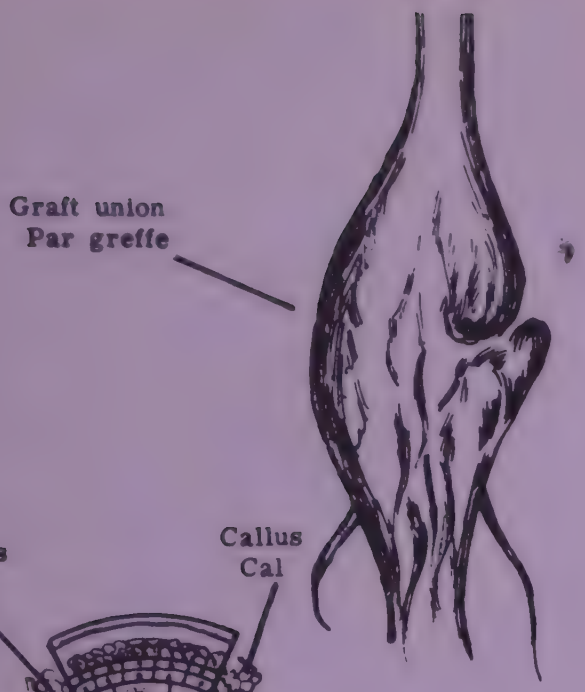
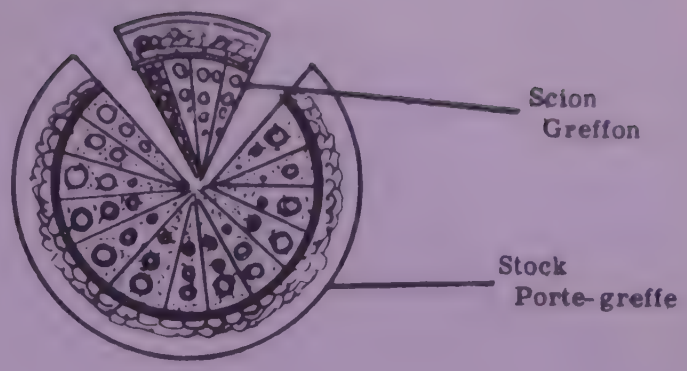
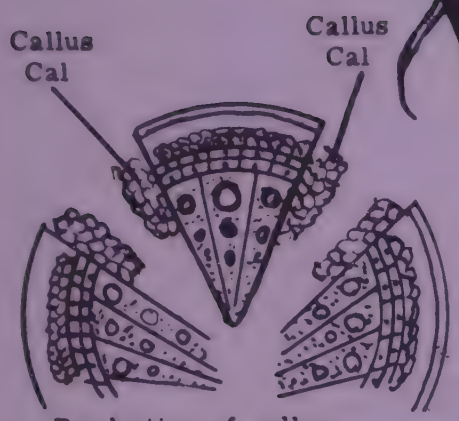


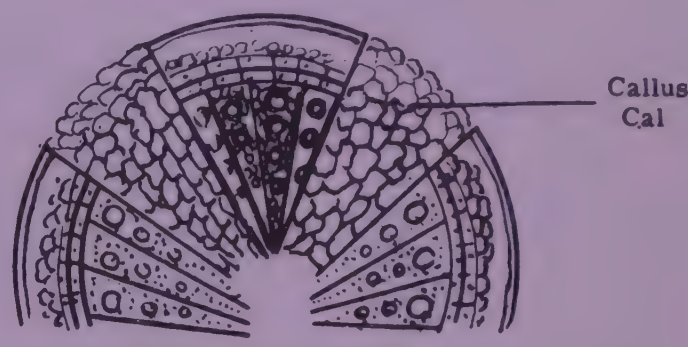
Fig. 50



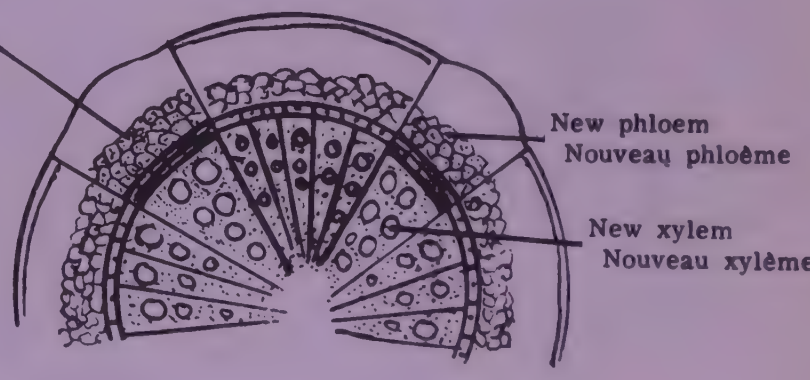




Production of callus by stock and scion
Production de cal par le porte-greffe et le greffon



Complete formation of callus interlocking the two components
Formation d'un cal complet unissant les deux éléments



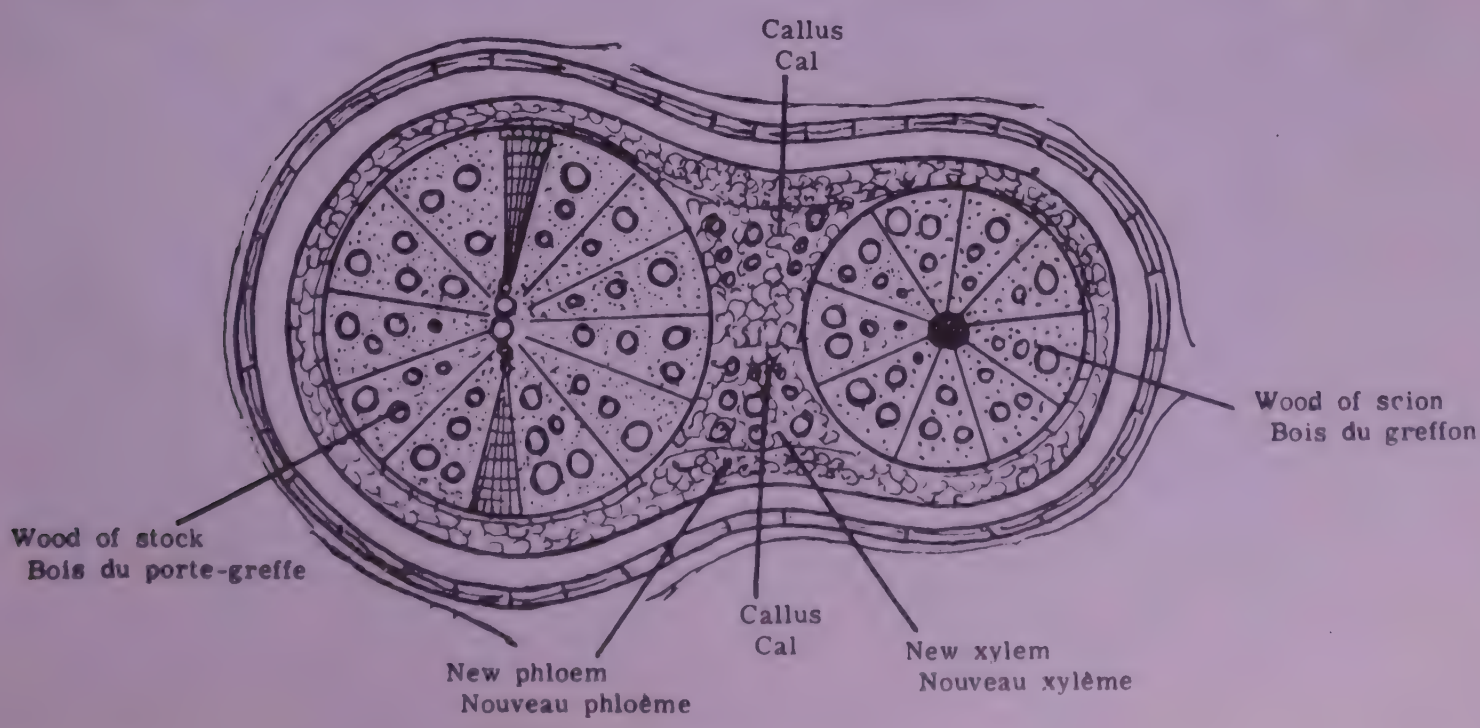


Fig. 51

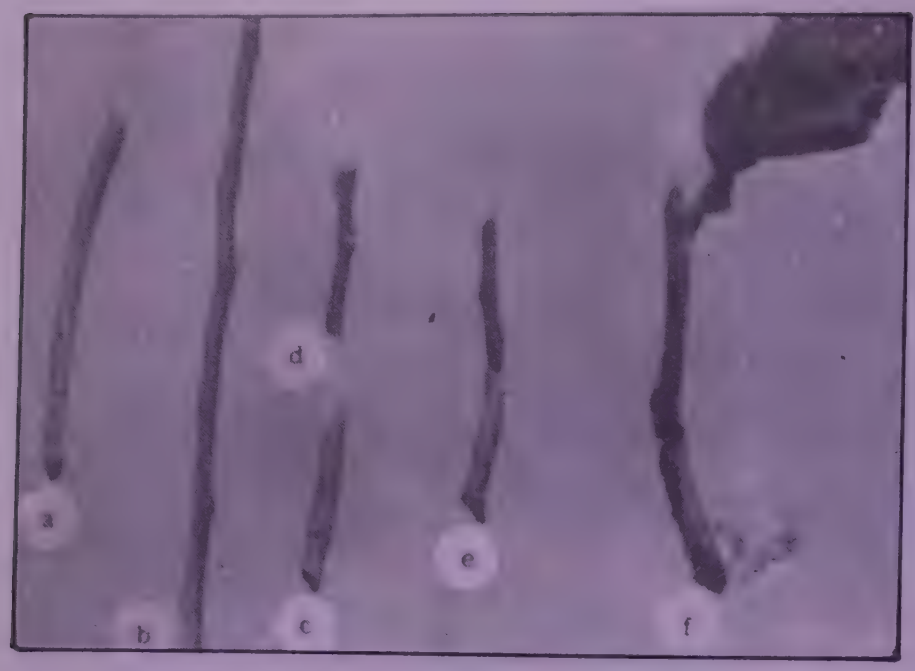


Fig. 53

Fig. 54

Fig. 52b

Fig. 52a

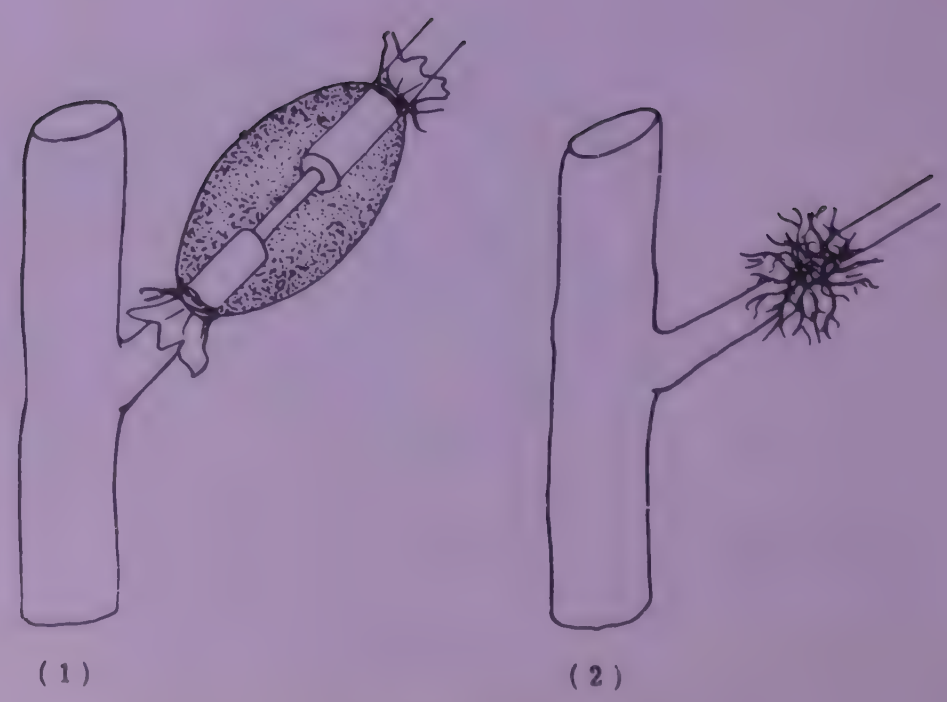


Fig. 56a

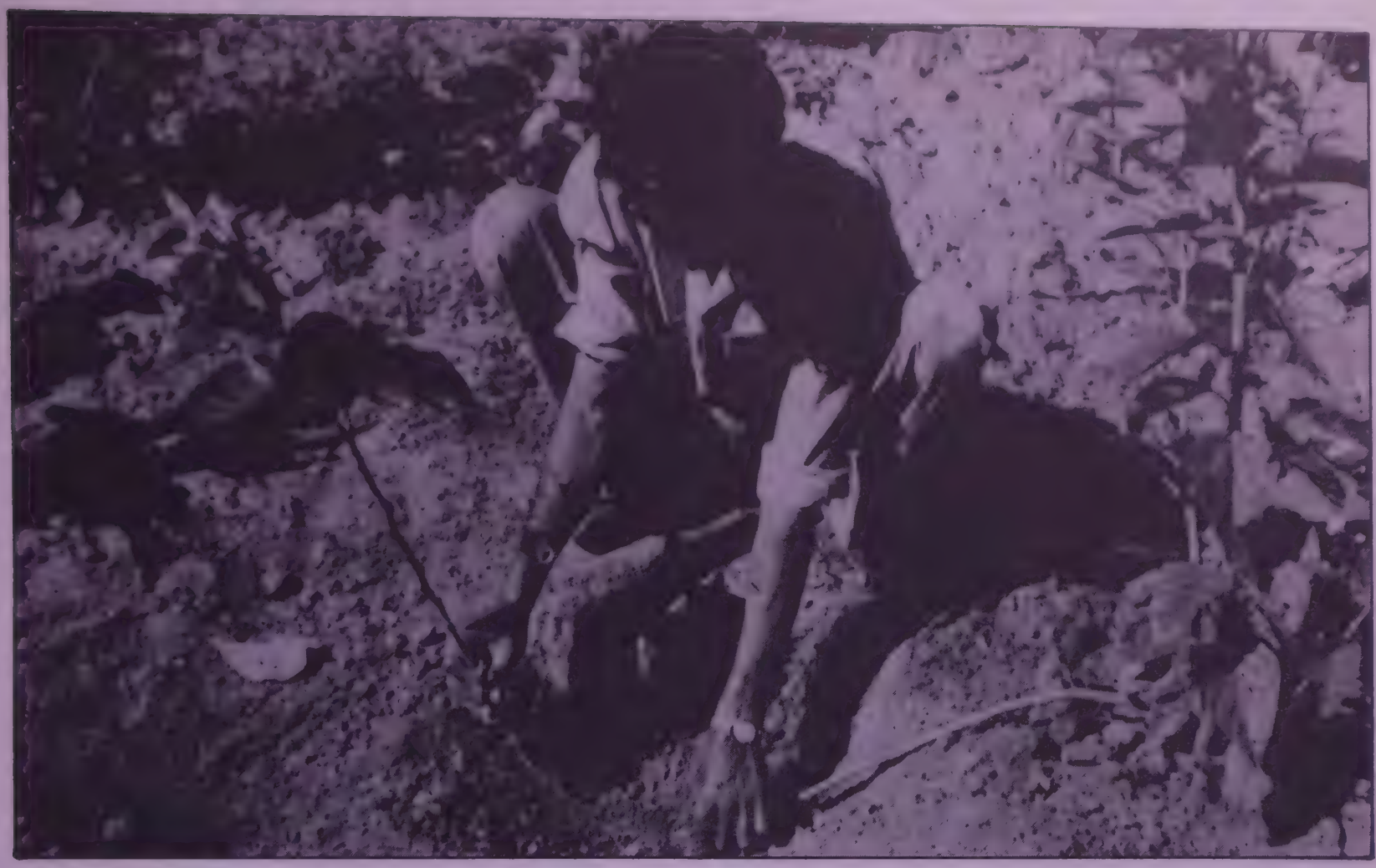
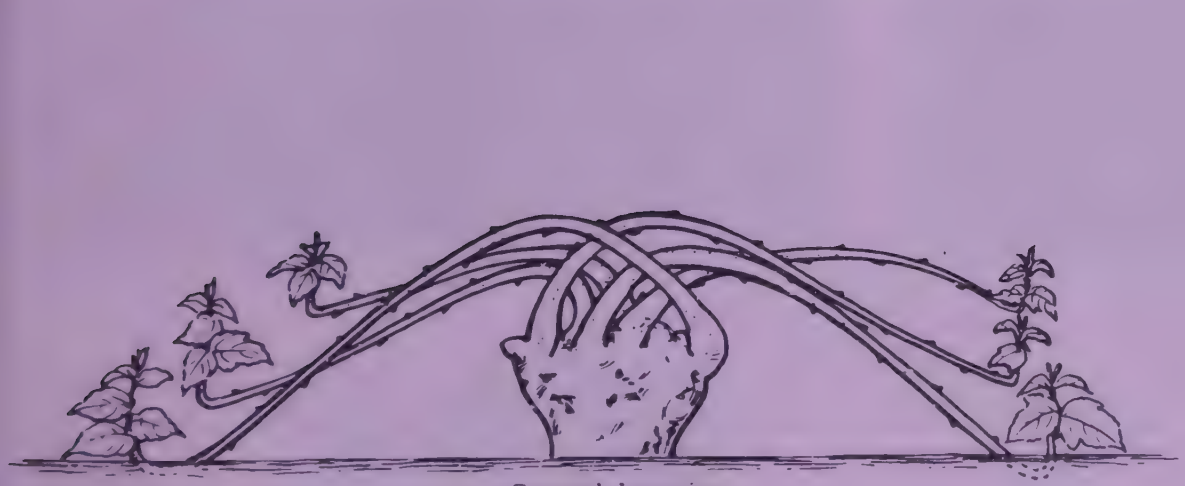
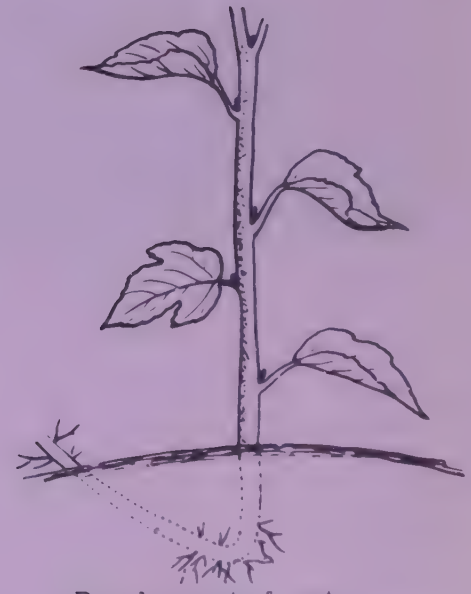


Fig. 55



Ground layering
Marcottage



Development of roots
Développement des racines

Fig. 56b

Rooted sapling
Plançon enracine

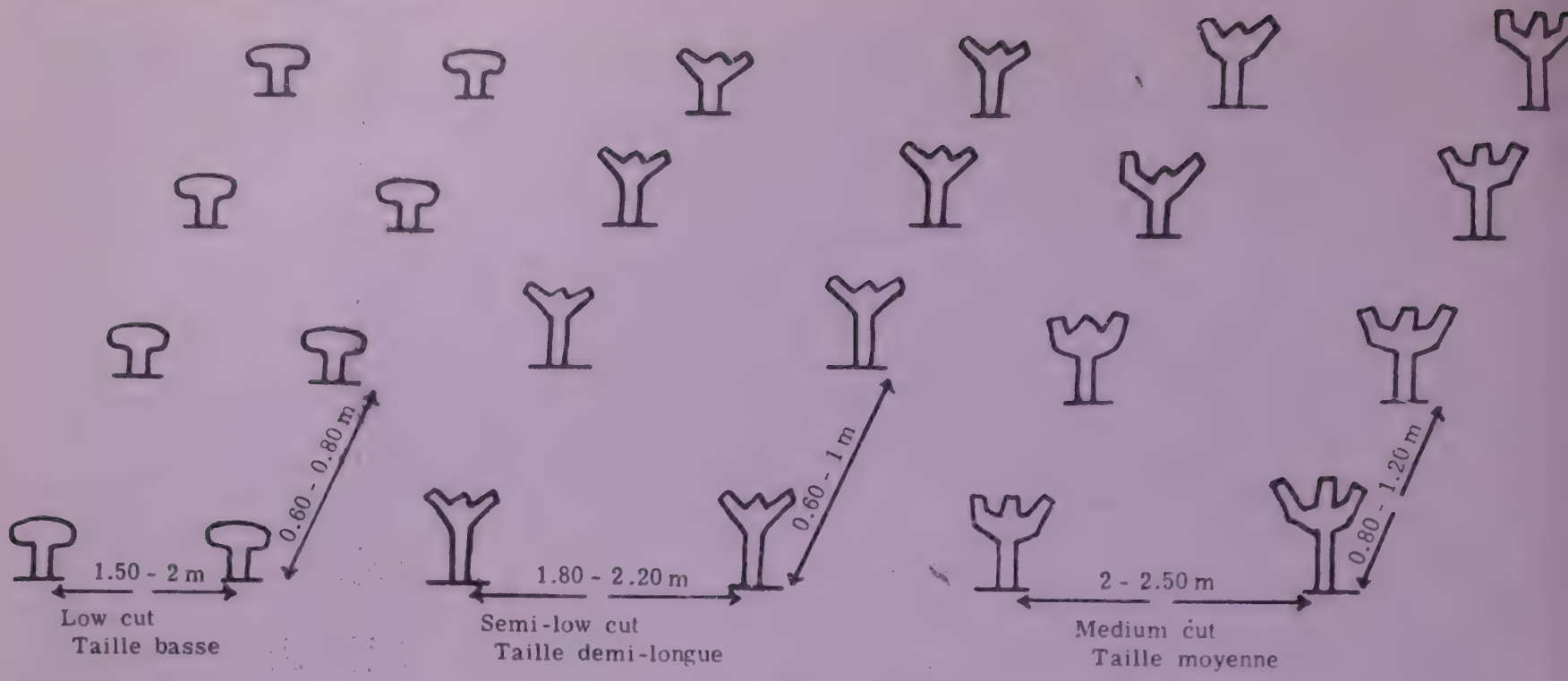


Fig. 57

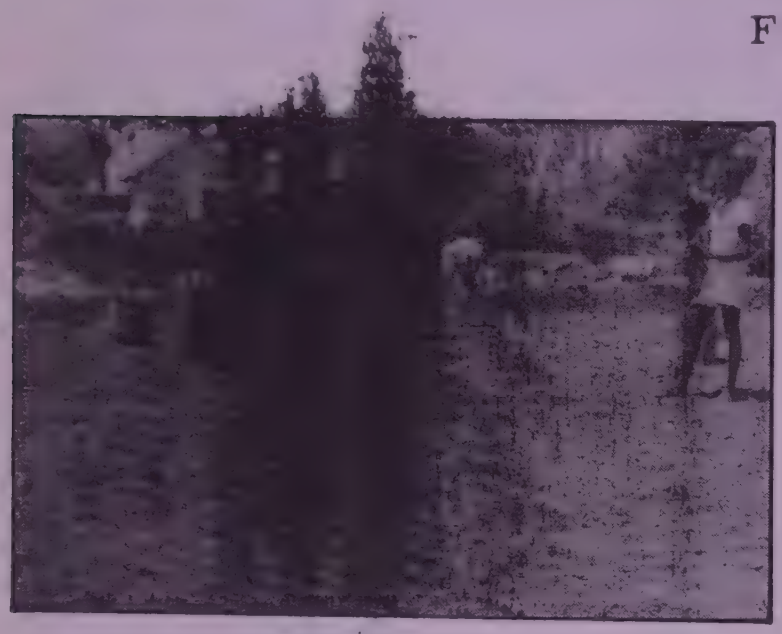
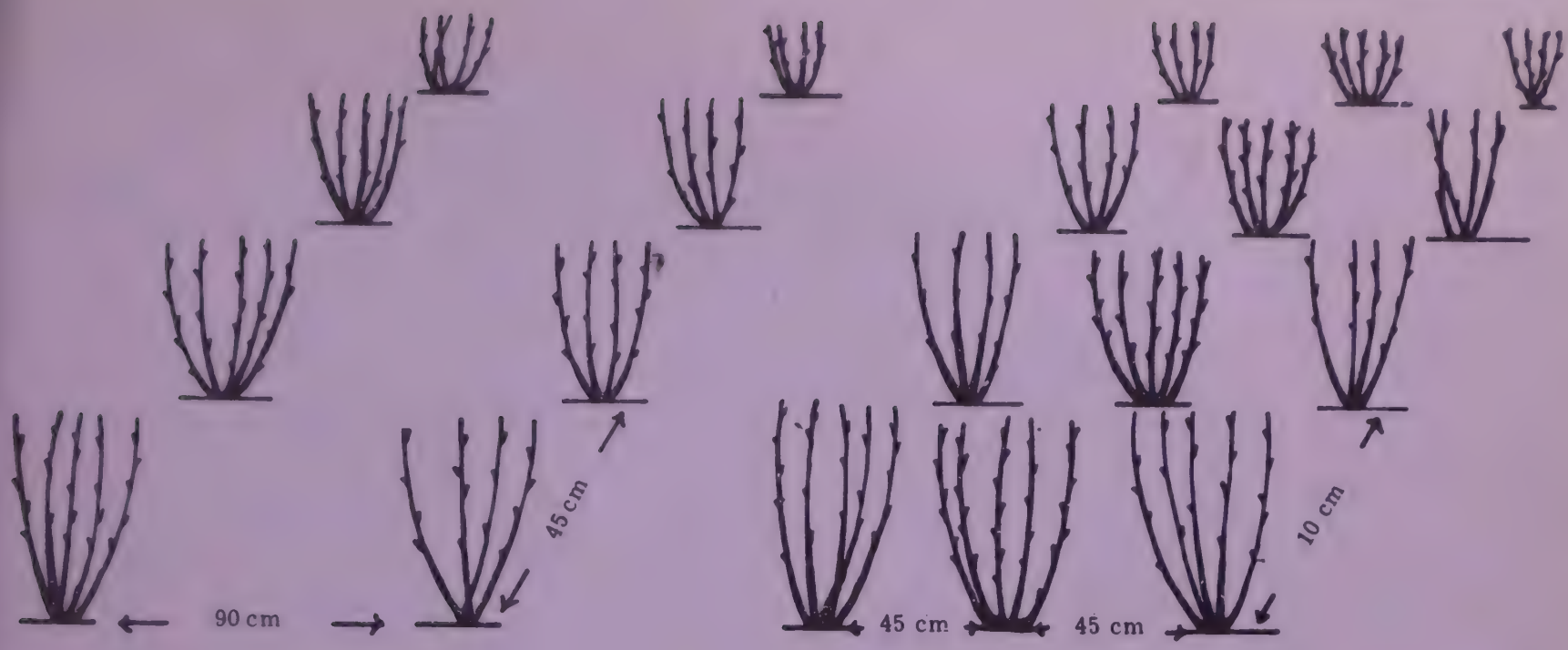


Fig. 59

Fig. 61

Fig. 60

Fig. 62



Pit system
Système en fosse

Row system (Kolar)
Système en ligne (Kolar)

Fig. 58

Fig. 63

Fig. 64

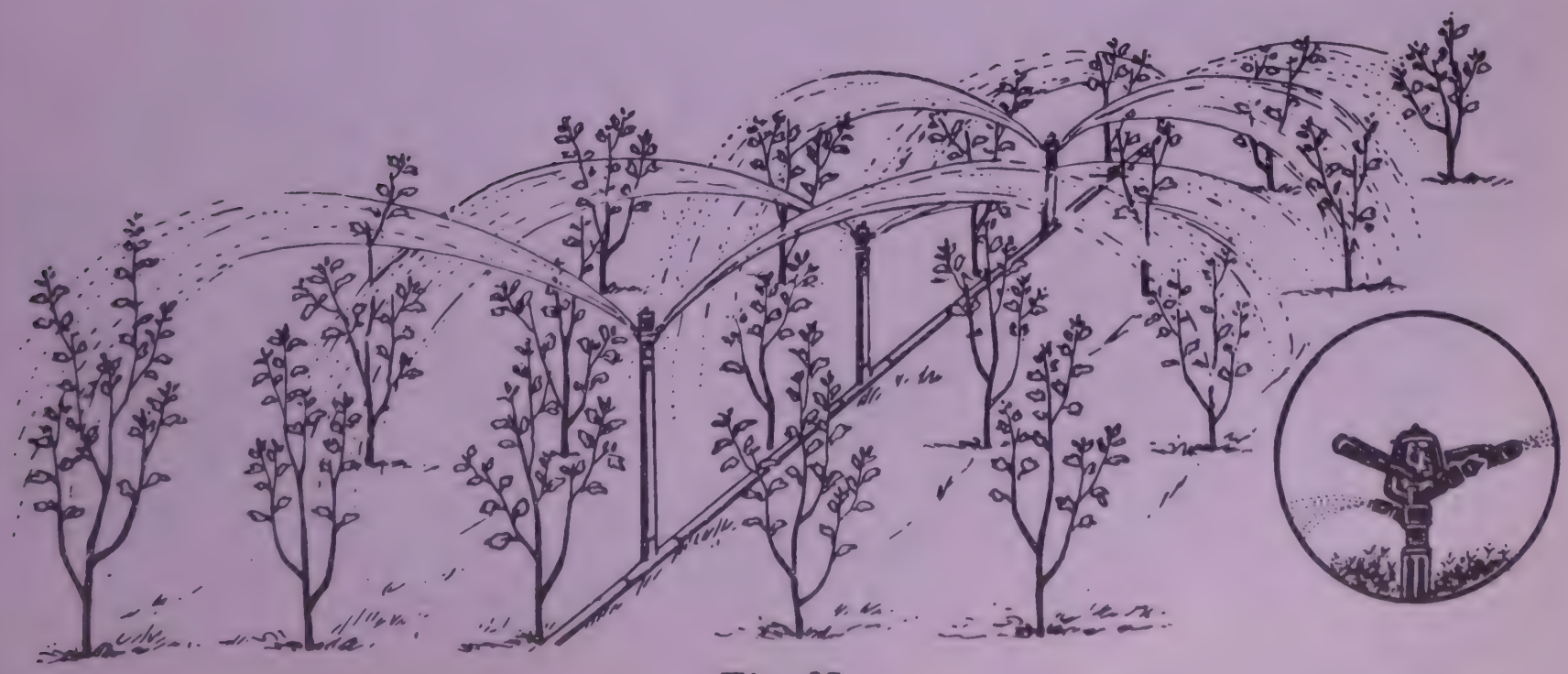


Fig. 65

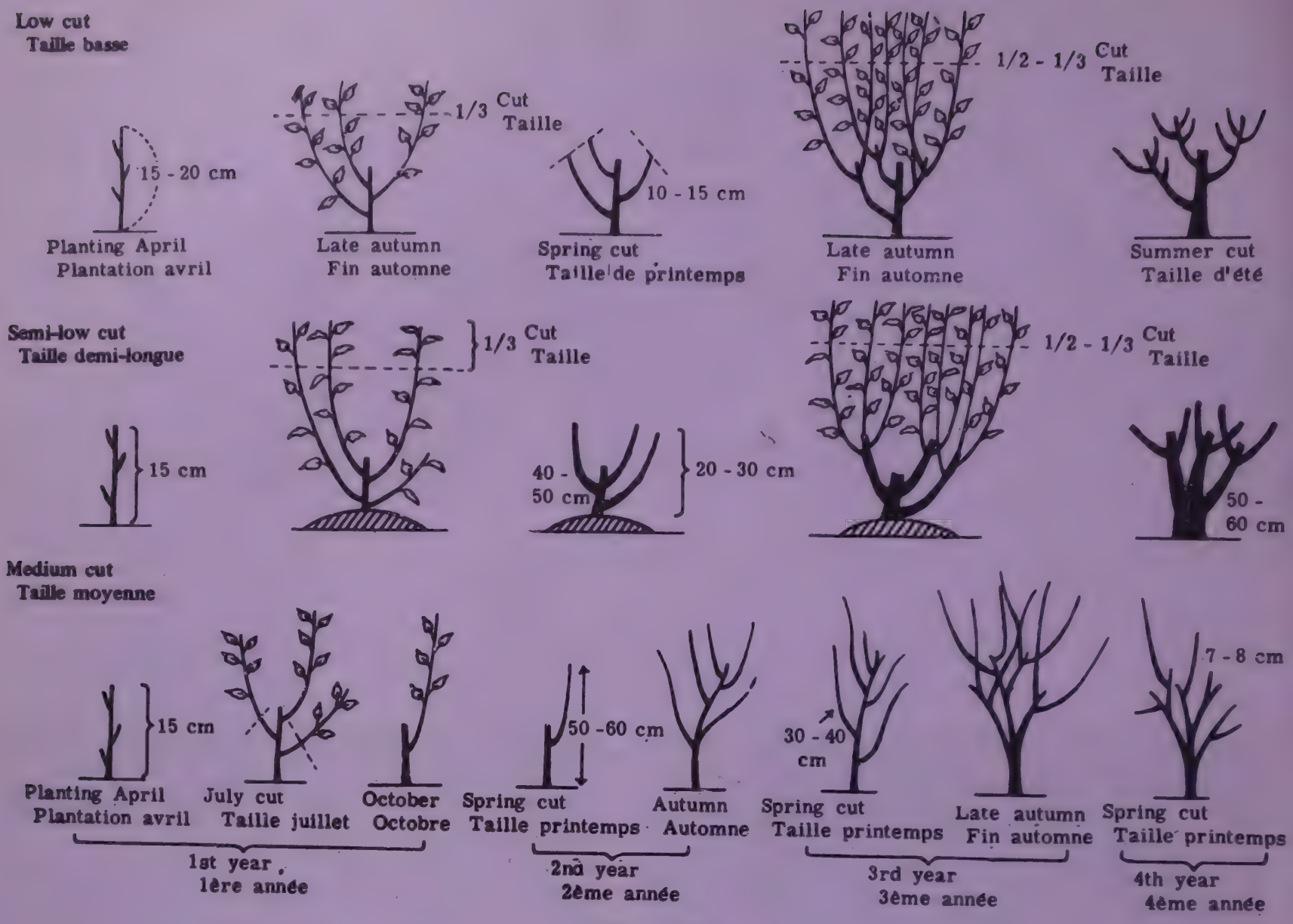
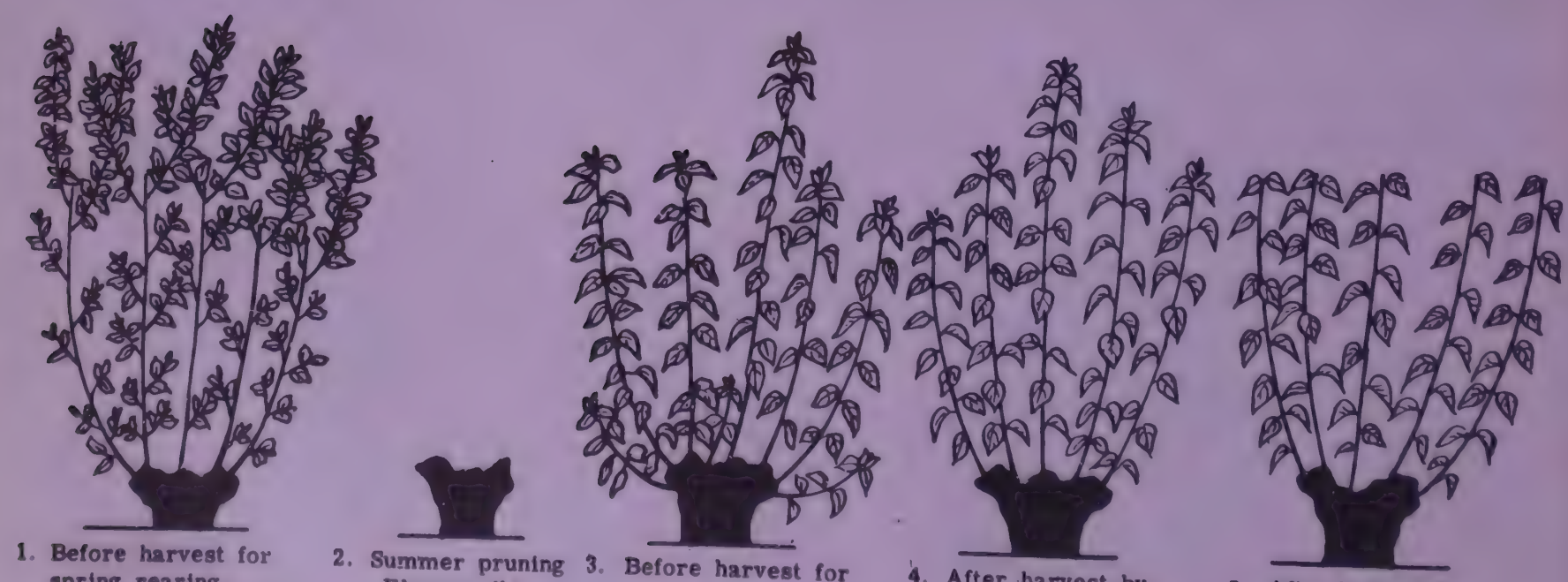


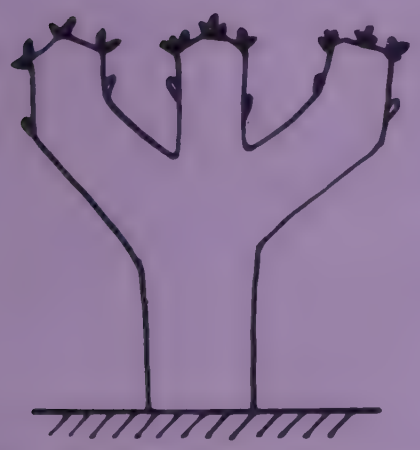
Fig. 66



1. Before harvest for spring rearing
   Avant récolte pour l'élevage de printemps
2. Summer pruning
   Elagage d'été
3. Before harvest for early autumn rearing
   Avant récolte pour l'élevage au début de l'automne
4. After harvest by thinning for early autumn rearing
   Après récolte par éclaircissage pour l'élevage au début de l'automne
5. After harvest for late autumn rearing (1/2-1/3 cut)
   Après récolte pour l'élevage en fin d'automne (taille 1/2-1/3)

Fig. 67

Fist form (old style)
Forme non évidée (ancien système)



Non-fist form (popular)
Forme évidée (la plus courante)

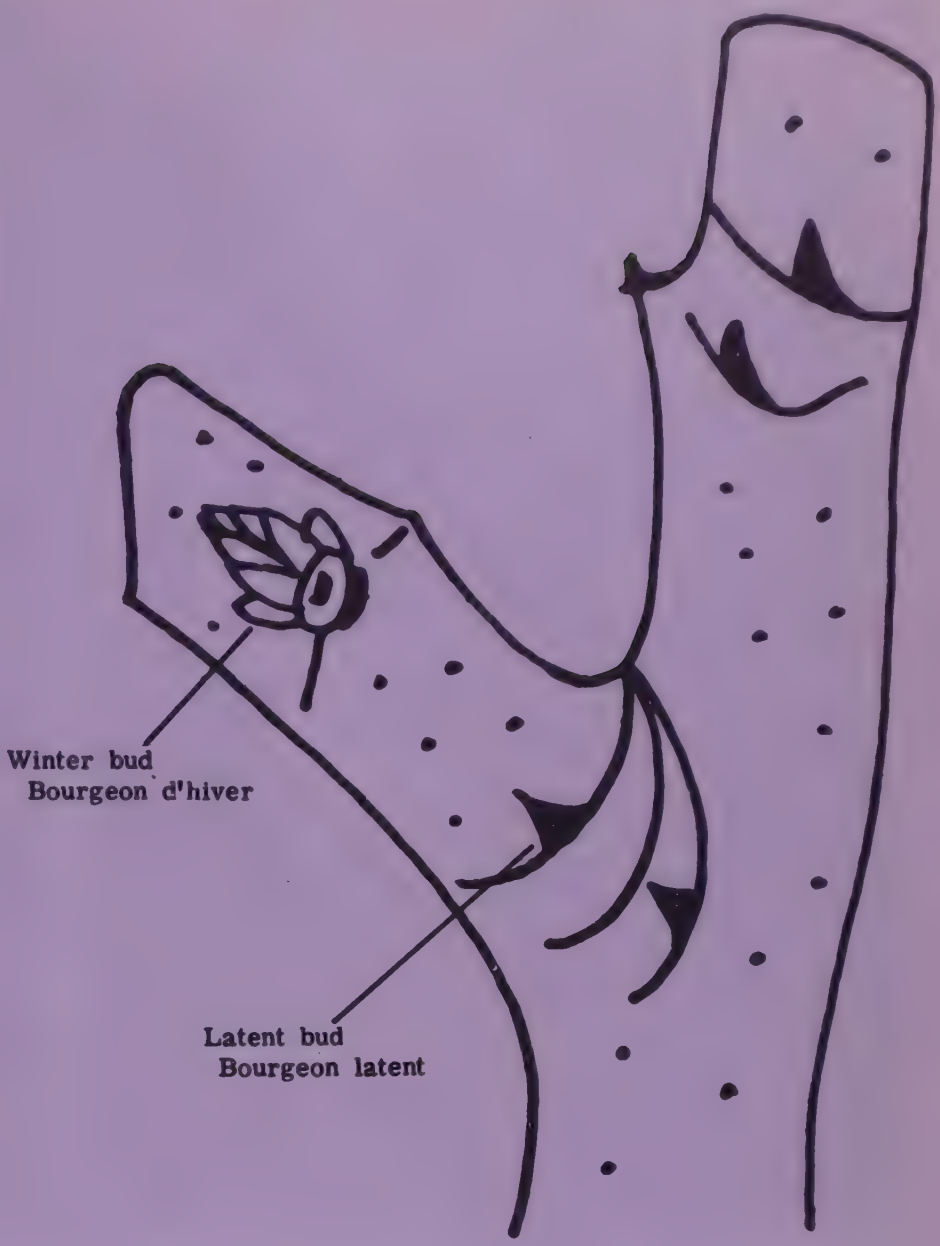


Fig. 69

1. Spring pruning
Elagage de printemps
2. Before harvest for early autumn rearing
Avant récolte pour l'élevage au début de l'automne
3. After harvest for early autumn rearing (thinning and half cut)
Après récolte pour l'élevage au debut de l'automne (éclaircissage et demi - taille)
4. Before harvest for late autumn rearing
Avant récolte pour l'élevage en fin d'automne
5. After harvest for late autumn rearing
Après récolte pour l'élevage en fin d'automne

Fig. 68

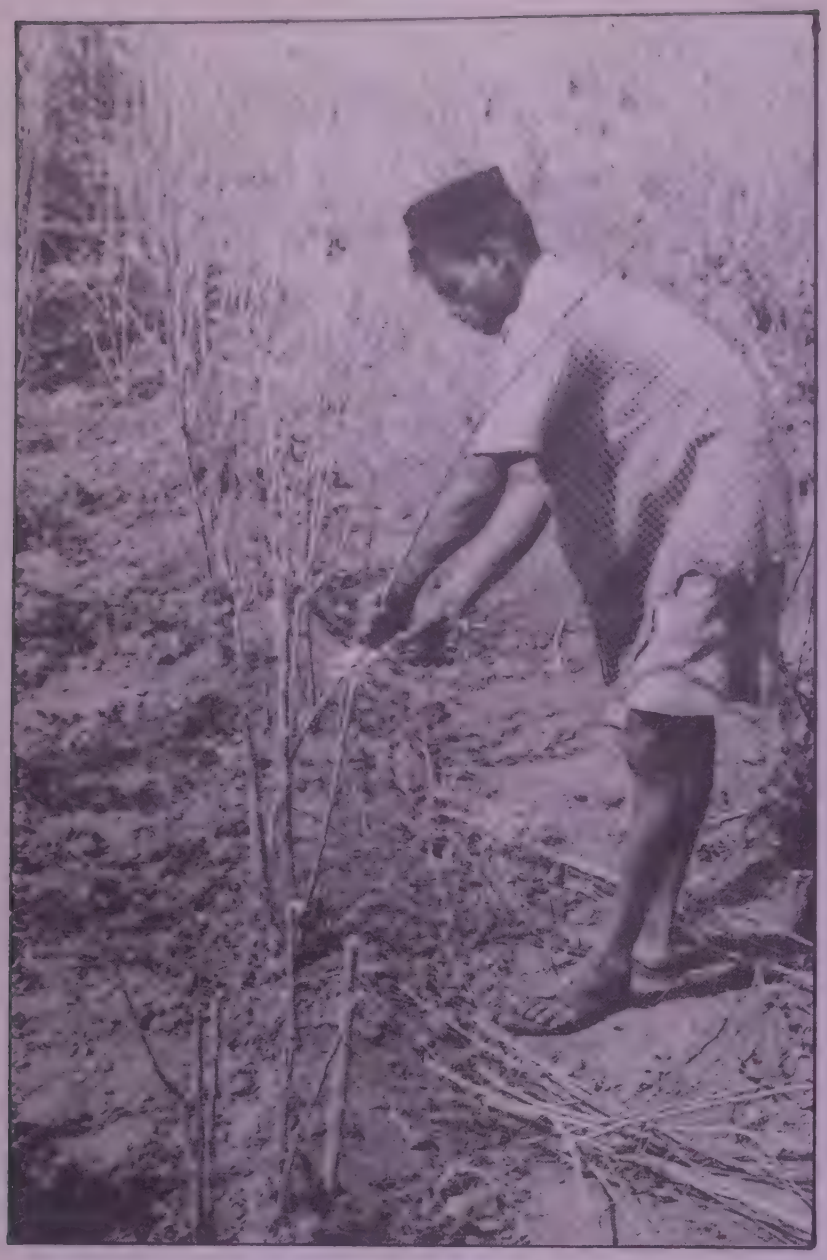


Fig. 70

Fig. 71

Fig. 72

Fig. 74

Fig. 75

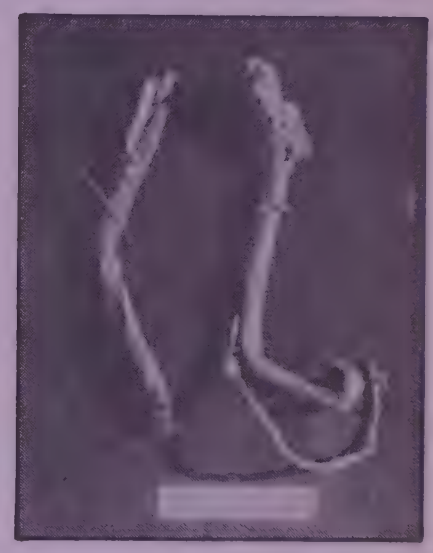


Fig. 76

Fig. 73

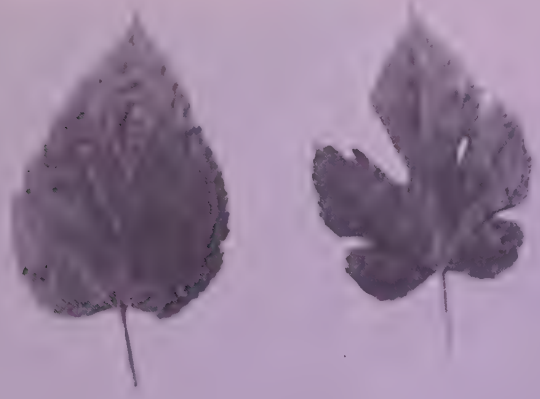
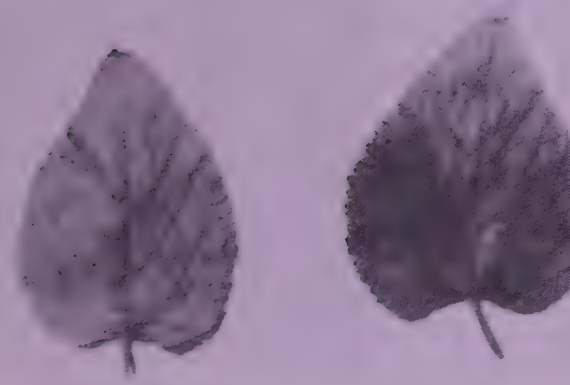


Fig. 77

Fig. 78



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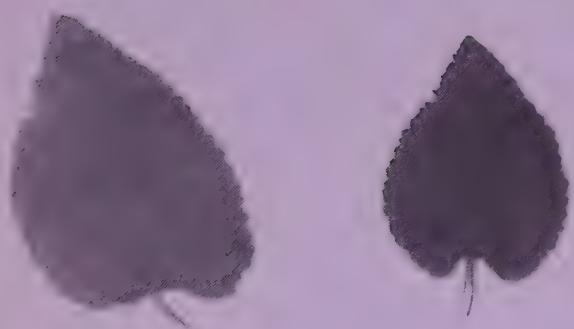

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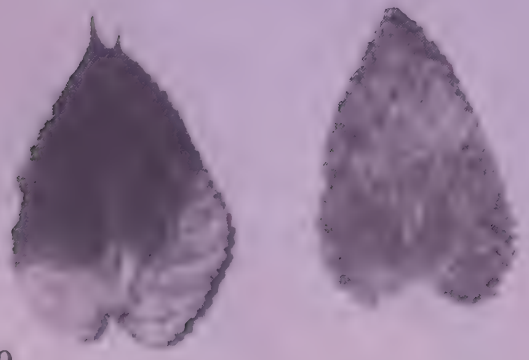


Fig. 81

Fig. 82a

Fig. 82b

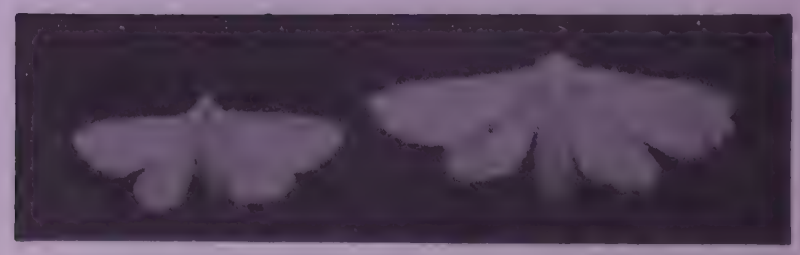


Fig. 82c

Fig. 83a

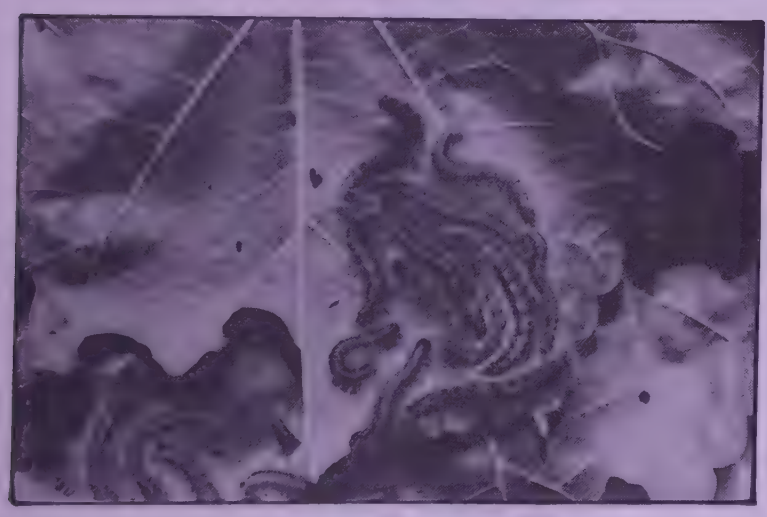


Fig. 83b

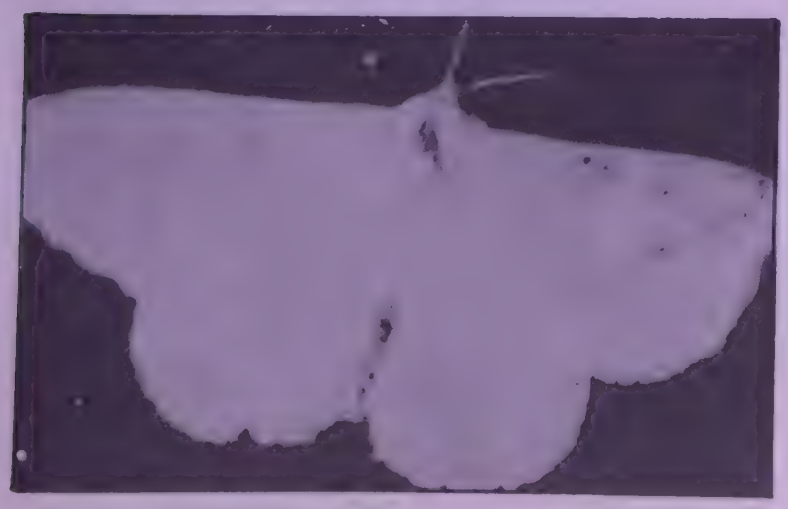


Fig. 83c

Fig. 84a

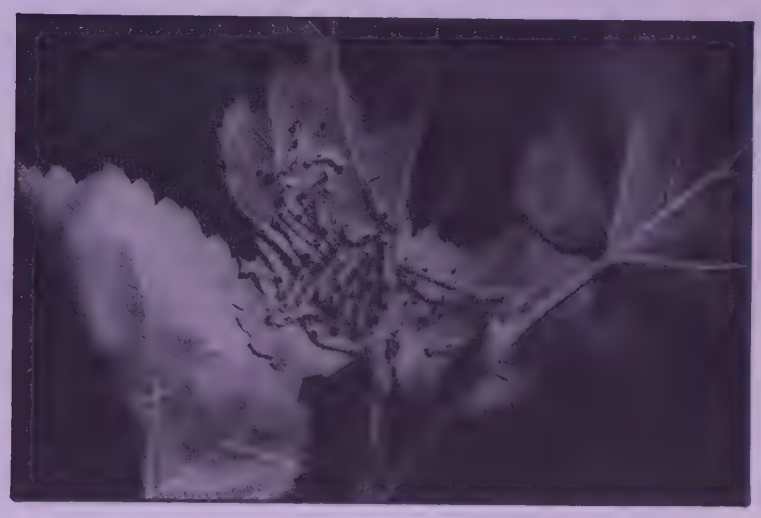


Fig. 84b

Fig. 84c

Fig. 85

Fig. 86a

Fig. 86b

Fig. 87a

Fig. 87b

Fig. 88

Fig. 90

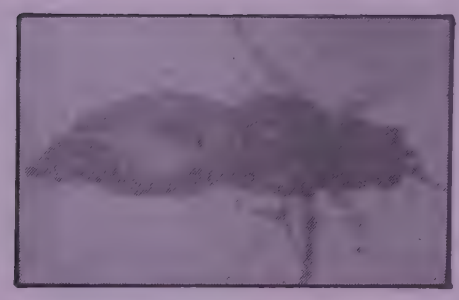


Fig. 91a

Fig. 91b

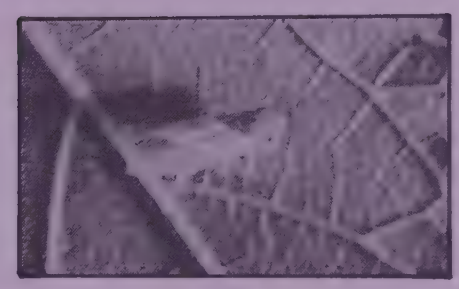
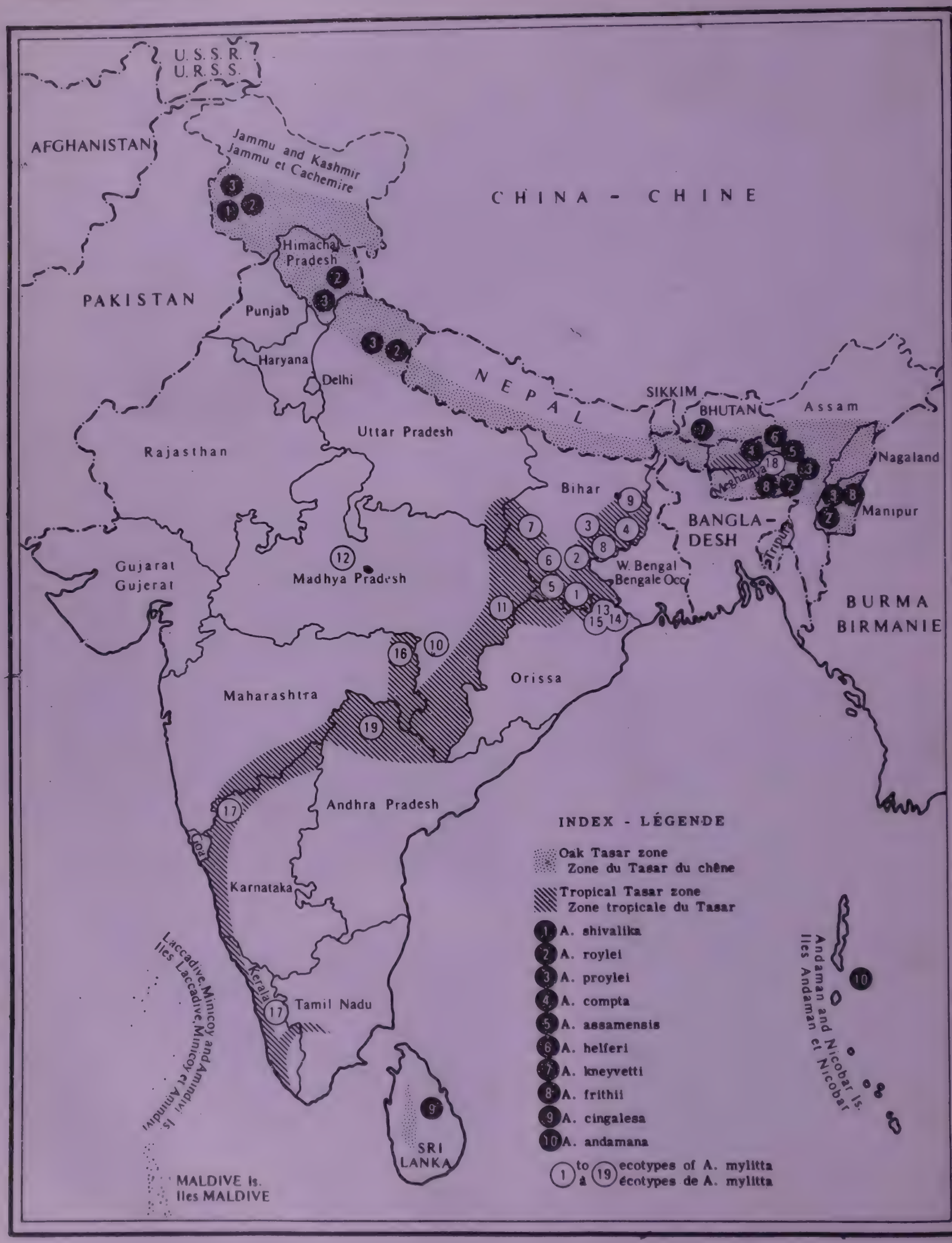


Fig. 92a

Fig. 89

Fig. 92b


U.S.S.R.
U.R.S.S.
AFGHANISTAN
Jammu and Kashmir
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Bengale Occ
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1 to à 19 ecotypes of A. mylitta
19 écotypes de A. mylitta

Fig. 93

Fig. 94

Fig. 95

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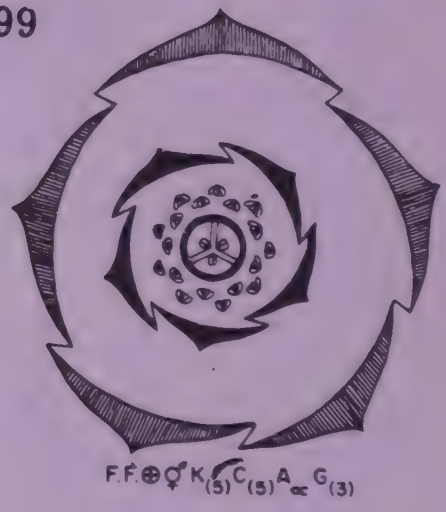
Fig. 98

Fig. 99



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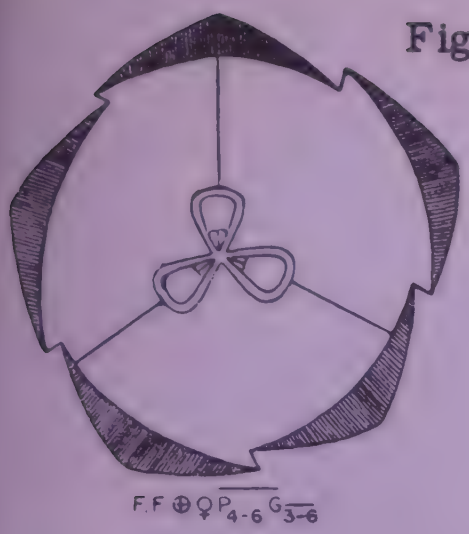

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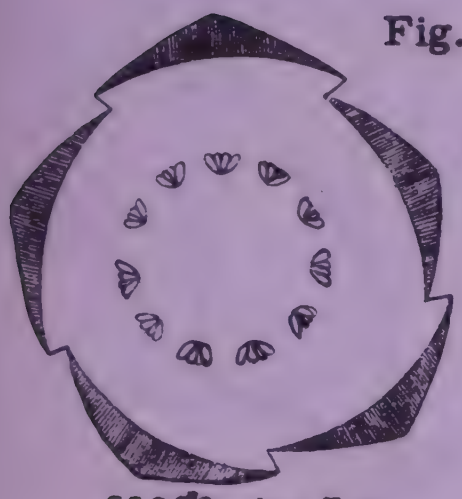

Fig 100

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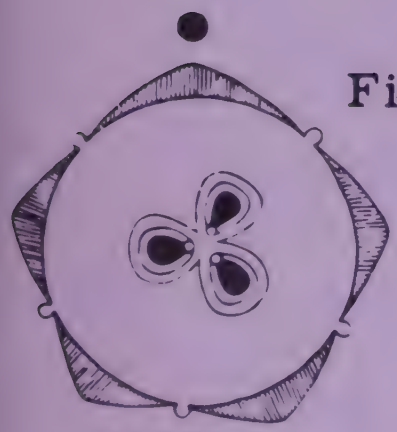

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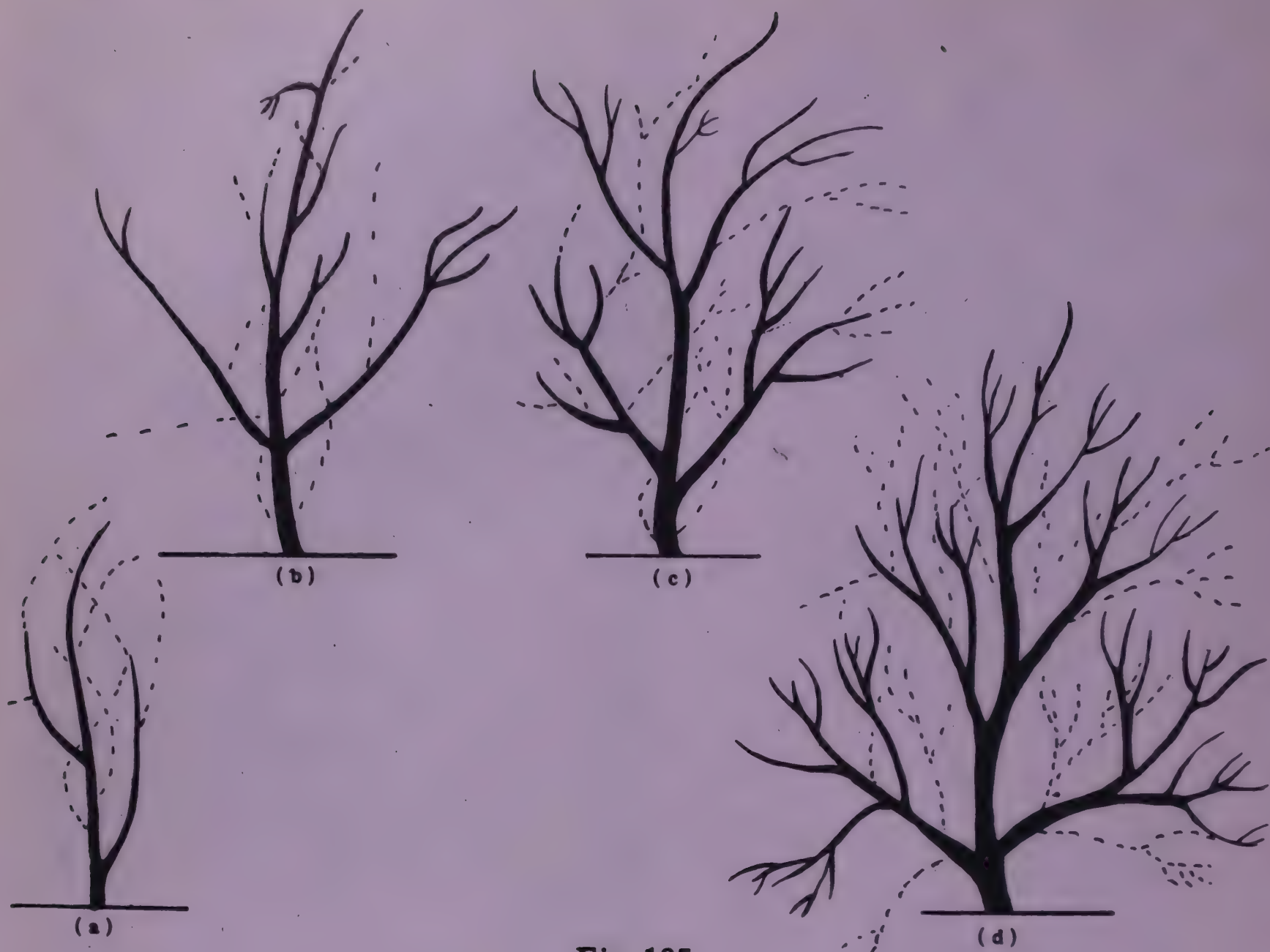

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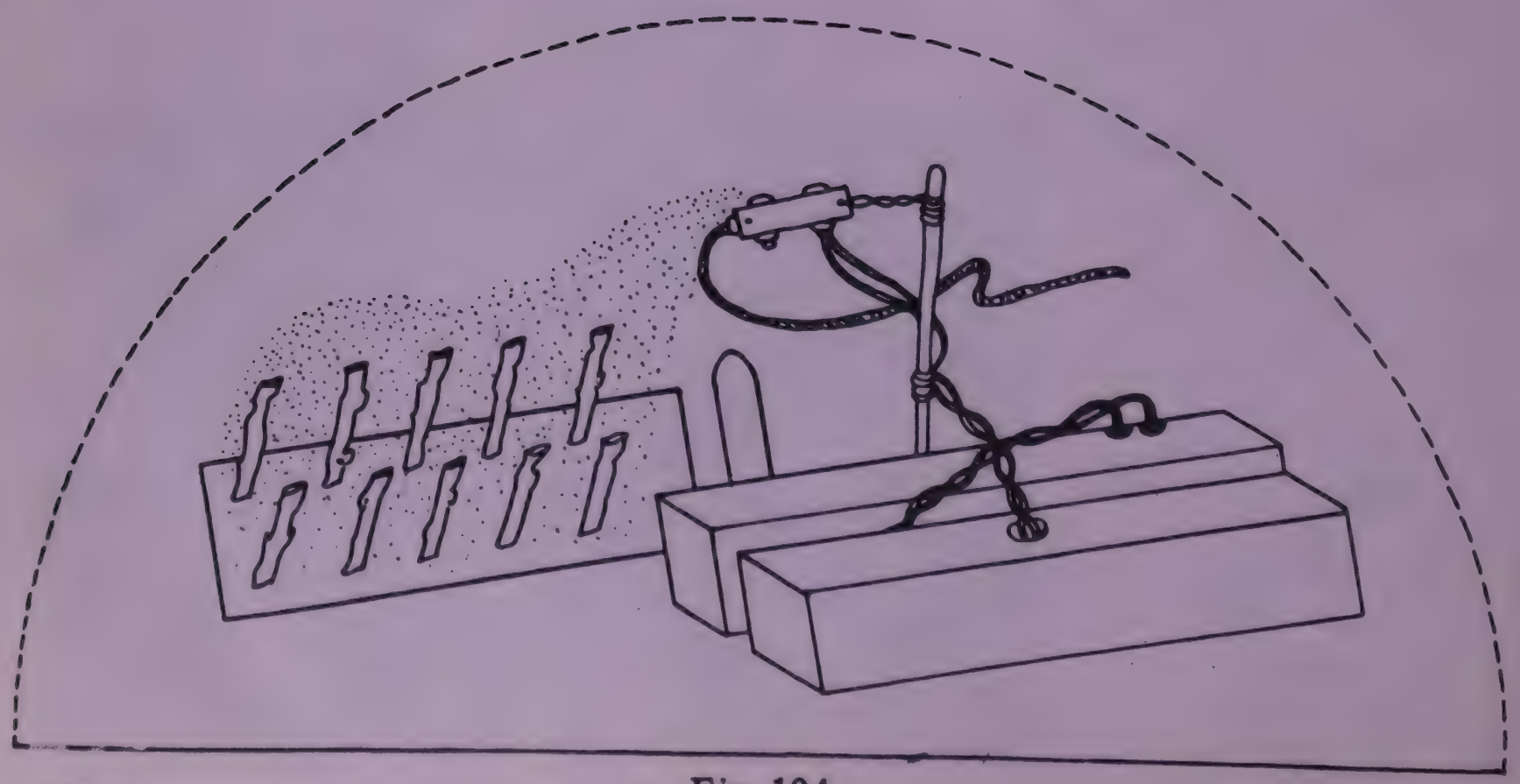

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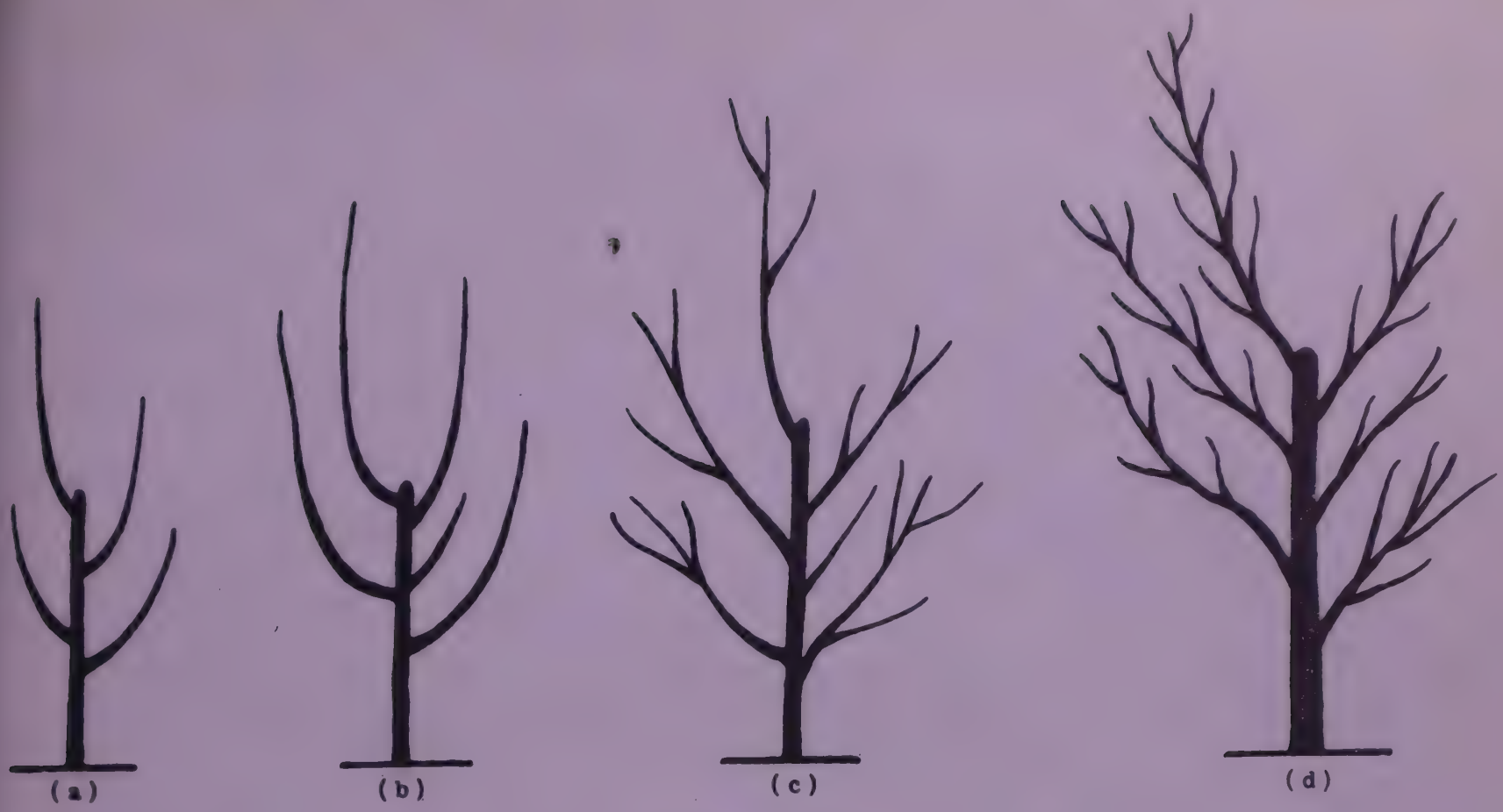

Fig. 106

Fig. 107

Fig. 108

FAO AGRICULTURAL SERVICES BULLETIN

FOOD AND AGRICULTURE ORGANIZATION
OF THE UNITED NATIONS ROME

Sericulture Manual
2 — Silkworm Rearing

sericulture manual
2 — silkworm rearing

by

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shri m. n. narasimhanna, assistant director
shri s. k. suryanarayan, senior research officer
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food and agricultural industries service
agricultural services division

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ROME 1973

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FOREWORD

In recent years, the governments of many developing countries have given added attention to the production of natural silk. Indeed, sericulture offers many advantages, such as:

a) helping to keep the rural population employed and to prevent migration to the towns.
b) securing remunerative employment,
c) earning much needed foreign currency,
d) requiring no large investments,
e) providing raw material for cottage and even large-scale textile industries.

One of the main obstacles to the development of silk production and the promotion of silk industries is the shortage of up-to-date literature. In order to help fill this gap, the Agricultural Services Division is preparing a *Manual on Sericulture* that will consist of three volumes:

Volume 1 — Mulberry Cultivation
Volume 2 — Silkworm Rearing
Volume 3 — Silk Reeling.

The present volume which deals with silk reeling is the first to be published; the other two will follow at the beginning and at the end of 1973, respectively. Readers are invited to submit suggestions and comments that would be useful in editing Volumes 1 and 2 to:

Chief, Food and Agricultural Industries Service
Agricultural Services Division
Food and Agricultural Organization of the United Nations
Via delle Terme di Caracalla
00100 Rome, Italy.

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Chapter–1

INTRODUCTION

Early history

Historical evidence shows that silk was discovered in China and that the industry spread from there to other parts of the world.

The earliest authentic reference to silk is to be found in the Chronicles of Chou-King (2200 B.C.) where silk figured prominently in public ceremonies as a symbol of homage to the emperors.

The silk industry originated in the province of Chan-Tong and the secret was jealously guarded by the Chinese for about 3,000 years. When commercial relations were established between China and Persia, and later other countries, the export of raw silk and silk goods assumed great importance. By the first century B.C. markets as far away as southern Europe began to receive silk fabrics made in the East.

According to some sources the first country after China to learn the secret was Korea, where Chinese immigrants started sericulture in about 1200 B.C. The industry later spread to Japan. According to another version, what was instrumental in bringing the silk industry to Japan during the third century B.C. when Semiramus, a general in the army of Empress Singu–Kongo, invaded and conquered Korea. Among his prisoners were some sericulturists whom he brought back to Japan. Under royal patronage the industry continued, though haltingly, till the Meiji Restoration in 1868. During the latter part of the 19th century Japan gave serious attention to the development of the industry, introducing the use of modern machinery and improved techniques and carrying out intensive research in sericulture. The industry is said to have spread to Tibet when a Chinese princess, carrying silkworm eggs and mulberry tree seeds in her headdress, married the king of Khotan in Tibet. From Tibet the industry spread slowly to India and Persia.

According to Western historians, mulberry–tree cultivation had spread to India through Tibet by about 140 B.C. and the cultivation of mulberry trees and the rearing of silkworms began in the areas flanking the Brahmaputra and Ganges rivers.

According to some Indian scholars silkworms (*Bombyx mori*) were first domesticated in the foothills of the Himalayas. There is also evidence in ancient Sanskrit literature that certain kind of wild silks were cultivated in India from time immemorial.

When the British came to India they found a flourishing silk trade. The British East India Company exploited the industry and developed silk centres in many parts of the country. The Company exported large quantities of the raw silk produced in West Bengal to England. The Company's monopoly was abolished in 1836 and the entire trade turned over to private enterprise which at that time was not properly organised and as a result the silk industry in Bengal declined. In the meantime other major silk–producing states namely Mysore, Jammu and Kashmir took steps to develop the industry.

The Arabs also were familiar with silkworms and even in Pre–Islamic times studied the life history of the silkworm. It has been suggested on the basis of early legends that the Arabs obtained silkworm eggs and mulberry–tree seed from India during the early part of the Christian era.

By the fourth century A.D. sericulture was well established in India and Central Asia. Raw silk and silken goods were exported from the East to Persia and then to Rome. The Persians held a monopoly on some of the silken goods most prized by Roman society but in the 6th century A.D. two monks from Rome, having learnt the art of sericulture in Tibet, introduced the industry into Constantinople in 553 A.D. The Romans were thus able to produce their own raw silk and this marked the beginning of silk production in Europe. For three or four centuries the rearing of silkworms was confined to the eastern areas of the Roman Empire and factories were set up in Athens, Corinth, and the Aegean Islands for manufacture of silk fabrics.

The industry moved gradually from the east to the Venetian Republic and by the end of the ninth century and during the tenth and eleventh centuries the Venetians developed the industry to such an extent that they were able to meet almost the entire requirements of Europe.

From Italy the industry spread to France where silkworm rearing was introduced in 1340 by French noblemen who brought in the silkworm eggs and the mulberry-tree seeds. The industry was firmly established in France by the end of the 17th century and prospered during the 18th century. In the 19th century, when sericulture was at its peak in France, an epidemic of pebrine — a destructive disease of silkworms — broke out and wiped out sericulture not only in France but throughout most of Europe and the Middle East.

Louis Pasteur's discovery in 1870 that the disease could be controlled by the examination of the mother moth for signs of pebrine saved the industry from extinction. Although the industry revived to some extent in France, it was not a complete revival mainly because of socio-economic changes and the Industrial Revolution.

Despite the efforts of James I and George I the industry was never firmly established in England or in the American colonies where the keen competition offered by tobacco and cotton proved too strong.

Economic importance

Silk has played an important role in the economic life of man ever since its discovery more than 4000 years ago. Fabulous silks from China and India were carried to Europe along the famous 6000-mile Silk Road, which passed through Tashkent, Baghdad, Damascus and Istanbul, and silk has been traditionally associated with the socio-economic life of many Asian and Central Asian countries. Even today, despite the onslaught of man-made fibres, silk continues to reign supreme as the "queen of textiles". Although produced in small quantities compared to other textile fibres both natural and man-made — less than 0.2 percent — it still holds a position of importance among the textile fibres, and is universally sought after for its elegance and colours by the world's top fashion designers. The demand for silk is steadily increasing and between 1960 and 1970 silk production and demand registered a growth rate of 2.5 per cent per annum.

Sericulture today is practised in industrially advanced countries such as Japan and the U.S.S.R. as well as in countries such as China, India, South Korea, which are now becoming industrialised. In the developing countries, it is essentially a village-based and welfare-oriented industry capable of providing employment to large sections of the population. Although sericulture had been considered for a long time as a subsidiary occupation in rural areas, recent technological developments have made it possible to practise sericulture on an intensive scale, producing greater profits than most of the agricultural crops.

Sericulture is being practised both as a subsidiary crop under unfavourable agro-climatic conditions and a highly paying crop, if necessary agricultural inputs can be ensured. Furthermore, since mulberry trees grow fast and in great abundance, two to three crops in temperate zones and four to six cocoon crops in tropical areas can be raised in a year and this will provide the ready cash required by the sericulturists throughout the year. Although up till now, sericulture has been practised mostly on small or medium-sized land holdings in most sericultural countries the remunerative returns from sericulture have opened up possibilities of establishing the industry on a plantation scale.

Silk also plays an important role as a foreign exchange earner for many of the silk producing countries of the world. For a period of about 70 years preceeding the second world war, silk used to head the list of Japan's exportable items, accounting for 30 to 50 per cent of her aggreage foreign exchange earnings. Silk figures prominently also in the exports of South Korea, China, Thailand and India and earns valuable foreign exchange for those countries. Recently with the export of raw silk from Japan falling drastically other newly developing countries are looking to silk as a potential foreign exchange earner and have taken up programmes for sericulture development seriously.

Distribution and world production

The main silk-producing countries of the world today are Japan, the People's Republic of China, The U.S.S.R. the Republic of Korea and India. Next in importance come ITaly, Bulgaria, Brazil, Iran, Turkey and Thailand, where sizeable quantities of raw silk are produced. Other minor countries where sericulture is practised include Rumania, Spain, Greece, Madagascar, Syria, the Khmer Republic, Hungary, Yugoslavia, Taiwan, etc.

Cocoon production

Figures for the world production of fresh cocoons are given in Table I for 1968–70 and for the pre-war level in 1938. It may be seen that cocoon production in 1970 was 23 percent below that of 1938, but showed a steady and gradual increase between 1968 and 1970. The main decline, between 1938 and 1970 have been in Japan, where production is less than half the 1938 level; and in Italy and Greece where cocoon production has falen to less than 10 per cent. There has also been a substantial decrease in Yugoslavia while the cocoon production seems to have almost disappeared in France.

On the other hand there have been significant increases in cocoon production in China, the U.S.S.R., India, Rumania, Syria and Spain. In China production almost doubled between 1938 and 1970. Figures for the three-year period 1968–70 show that there was a gradual decline in cocoon production in Japan, Italy and Turkey, whereas there was steady increases in China, India, the Republic of Korea and Brazil. In the U.S.S.R. production was more or less steady.

Table I — World Production of Cocoons *

	1938	1968	1969	1970
	Tons			
China, People's Rep. of	65,520	111,200	120,900	125,000
Japan	282,211	121,014	113,996	110,744
U.S.S.R	22,343	36,100	35,700	36,000
India	9,404	25,975	25,565	30,000
Korea, Rep. of	21,893	16,615	21,244	22,000
Brazil	403	1,610	2,156	2,200
Iran	3,000	2,100	2,200	2,200
Bulgaria	2,173	2,004	2,249	1,979
Italy	19,990	2,950	2,279	1,594
Turkey	2,346	1,710	1,662	1,461
Rumania	200	608	718	700
Pakistan	—	600	600	600
Syria	100	317	370	361
Spain	193	345	330	340
Khmer Republic	—	240	240	240
Greece	3,489	92	236	204
Madagascar	—	200	200	200
Yugoslavia	530	165	170	160
Taiwan	—	144	142	140
Hungary	267	100	110	110
Lebanon	850	104	100	90
Poland	11	43	69	89
Egypt, Arab Rep. of	—	99	75	83
German Dem. Rep.	—	11	11	11
Czechoslovakia	—	10	10	5
Ryuku Is.	—	6	6	5
France	597	6	N.A. **	N.A. **
World total	438,832	324,368	331,338	336,516

* Source: Silk in India — Statistical Biennial 1972.

** N.A. — Not available.

World trade in cocoons

There is very little world trade in cocoons, practically all of the output being reeled in the producing countries themselves. The 1969 statistics indicate that less than 3000 tons of cocoons were exported, representing less than one percent of world production.

Raw silk production

Global output of raw silk in 1970 was 40254 metric tons. World production figures for raw silk in 1938 and between 1968 and 1970 are given in Table II. Although the 1970 raw silk production was lower than the 1938 production by over 16000 tons, production between 1968 and 1970 has steadily and significantly gone up indicating the increasing world demand for silk.

Between 1938 and 1970 raw silk production was considerably lower in Japan, Italy, Greece, France and Lebanon. On the other hand, substantial increases have taken place in the People's Republic of China, the U.S.S.R. the Republic of Korea, India and Brazil.

During the three-year period 1968–70 raw silk production declined in Italy, while it remained more or less steady in Japan and the U.S.S.R. In the case of the People's Republic of China, the Republic of Korea, India and Brazil there have been steady increases in production.

These trends in raw silk production are in line with the trends in cocoon production.

Table II — World Production of Raw Silk

	1938	1966	1967	1968	1969	1970
			Metric tons			
HIGH-INCOME COUNTRIES						
Bulgaria	180	248	245	247	250	* 245
France	105	—	—	—	—	—
Greece	255	55	** 46	** 53	** 55	** 45
Hungary	20	17	12	9	6	4
Italy	2 738	593	478	523	499	310
Japan	43 152	18 694	18 926	20 755	** 485	20 515
Poland	1	* 7	* 7	* 8	* 7	* 7
Romania	15	* 90	* 79	* 61	* 72	* 70
Spain	15	42	46	31	29	* 31
U.S.S.R.	1 900	2 644	2 782	2 930	2 930	* 2 940
Yugoslavia	45	50	34	34	29	18
Sub-total	48 426	22 440	22 655	24 641	25 362	24 185

Table II (cont)

	1938	1966	1967	1968	1969	1970
			Metric tons			
LOW-INCOME COUNTRIES						
Brazil	33	135	147	187	233	* 259
China, People's Rep. of	4,853	*** 7,180	*** 7,770	*** 8,450	*** 9,025	*** 11,124
Egypt	—	10	10	10	8	9
India	691	1,502	1,668	1,745	1,758	2,250
Iran	210	* 124	* 134	* 160	* 185	210
Khmer Republic	—	* 20	* 20	* 20	* 20	* 20
Korea, Rep. of	1,824	1,154	1,329	1,687	2,403	2,846
Lebanon	21	* 9	* 10	* 10	* 10	* 15
Madagascar	—	*9	* 10	* 15	* 15	* 15
Pakistan	—	* 40	* 40	* 40	* 40	* 40
Syrian Arab Rep.	8	* 8	* 8	* 10	* 12	* 11
Thailand	—	* 50	* 80	* 115	* 165	200
Turkey	213	* 114	* 157	* 244	* 137	* 120
Sub-total ****	3,178	10,387	11,398	12,708	14,024	17,130
WORLD TOTAL ****	56,457	32,827	34,053	37,349	39,386	41,315

* Estimated by FAO — ** Estimated on basis of information from Greek Ministry of Agriculture

*** Estimated from a Japanese source. **** Total includes estimate for other countries for which data are not available.

Source: FAO Monthly Bulletin of Agricultural Economics and Statistics, Vol. 21, No. 12, December 1972.

Table III — Exports of Raw Silk

	1966	1967	1968	1969	1970
	Metric tons				
HIGH-INCOME COUNTRIES					
Bulgaria	146	144	283	287	290
France	54	50	43	62	49
Germany, Fed. Rep. of	2	4	1	—	5
Italy	384	560	495	474	589
Japan	527	224	566	184	75
Romania	50	40	35	8	8
Switzerland	93	100	58	104	49
United Kingdom	21	11	11	16	23
United States	2	36	19	5	57
Yugoslavia	32	25	4	—	—
Sub-total	1 311	1 194	1 515	1 140	1 145
LOW-INCOME COUNTRIES					
Brazil	21	40	48	104	170
China, People's Rep. of	3 700	3 800	3 900	4 900	4 800
Hong Kong	135	18	32	33	24
India	—	—	3	33	—
Korea, Rep. of	808	919	1 056	1 644	2 036
Syrian Arab Rep.	5	5	5	3	16
Turkey	85	52	28	18	46
Sub-total	4 758	4 835	5 072	6 735	7 092
WORLD TOTAL	6 069	6 069	6 587	7 875	8 237

Source: FAO Monthly Bulletin of Agricultural Economics and Statistics, Vol. 21, No. 12, December 1972.

Raw silk imports

Table IV indicates the global imports of raw silk for the period 1966–70. The main importers of raw silk are the developed countries, which increased their imports appreciably between 1966 and 1970. The largest increase was in imports into Japan, who has changed from a net exporter to a net importer of raw silk since 1916. Since 1966 Japan has more than trebled her imports. On the other hand, imports into the U.S.A. have declined substantially due to inroads made by man-made fibres. Silk-consuming countries of Western Europe imported less silk in 1970, the largest decline being in France and Switzerland.

Table-4 — Imports of Raw Silk

	1966	1967	1968	1969	1970
HIGH-INCOME COUNTRIES			Metric tons		
Australia	1	1	—	2	1
Austria	1	1	—	1	1
France	771	715	707	736	619
Germany, Fed. Rep. of	202	214	233	248	183
Italy	1 861	1 807	1 461	1 963	1 851
Japan	1 138	1 742	1 225	2 578	3 874
Japan-wild silk	—	—	—	1	2
Netherlands	—	—	—	1	2
Spain	34	41	18	12	11
Switzerland	435	502	364	309	224
United Kingdom	210	192	211	198	185
United States	1 687	1 168	1 051	906	457
Yugoslavia	—	—	2	2	2
Sub-total	6 340	6 383	5 653	7 443	7 730
LOW-INCOME COUNTRIES					
Egypt	11	7	2	23	25
Hong Kong	106	68	81	88	44
India	45	42	37	58	28
Khmer Republic	49	2	15	10	10
Thailand	—	—	—	220	200
Sub-total	211	119	135	397	307
WORLD TOTAL	6 551	6 502	5 788	7 842	8 107

Source: FAO Monthly Bulletin of Agricultural Economics and Statistics, Vol. 21. No. 12, December 1972.

Outlook for silk

A study made by FAO has placed the estimated demand for 1980 at 48 000 metric tons. According to this study the trend in production of raw silk is expected to continue downward in developed countries and upward in developing countries. In Japan, while the production may fall to 17 000 tons by 1980 the demand is expected to rise to 28 000 tons, Although Japan is a leading producer of synthetic fibres and has also taken to washing machines in a big way and should normally opt for easy–care fabrics, the silk kimono retains a high status value and is still much favoured and therefore the easy–care properties of synthetic fibres are subordinate to the traditional appeal of pure silk.

It is also encouraging to note that the FAO study predicts a more than two fold growth in demand for raw silk by the U.S.A. in 1980 over the 1970 level. In Italy, France, the United Ingdom, Switzerland and Germany a normal rise in demand has been anticipated.

Chapter 2

SILK WORMS

(i) Kinds of silkworms

There are four kinds of natural silk which are commercially known and produced. Among them mulberry silk is the most important and contributes as much as 95 per cent of world production, therefore, the term "silk" in general refers to the silk of the mulberry silkworm. Three other commercially important kinds fall into the category of non–mulberry silk namely: **eri** silk; **tasar** silk; and **muga** silk.

Mulberry silkworms

The insect producing mulberry silk is a domesticated variety of silkworm which has been exploited for over 4000 years. All the strains reared at present belong to the species *Bombyx mori* which is believed to have been derived from the original *Mandarina* silkworm, namely *Bombyx mandarina* Moore.

The mulberry silkworm may be further classified and identified as of Japanese, Chinese, European or Indian origin based on geographical distribution, or as univoltine, bivoltine and multivoltine depending upon the number of generations produced in a year under natural conditions; or as tri–moulters, tetramoulters and pentamoulters according to the number of moults during larval growth; or finally even as pure strains, and as hybrids which may be either monohybrid when two strains are involved or polyhybrids when more than two strains are nvolved in the hybrid.

Bombyx mori produces cocoons with continuous silk filament and therefore can be industrially reeled to produce raw silk.

Eri silkworms:

These belong to either of two species namely *Philosamia ricini* Hutt or *Philosamia cynthia* Drury which are closely related to each other. *P. cynthia* is a wild species while *P. ricini* (also called as castor silkworm) is a domesticated one reared on castor oil plant leaves so as to produce a white or brick–red silk popularly known as **eri** silk. Since the filament of the cocoons spun by these worms is neither continuous nor uniform in thickness, the cocoons cannot be properly reeled and, therefore, the moths are allowed to emerge and the pierced cocoons are used for spinning purposes to produce the **eri** silk yarn.

Tasar silkworms:

The **tasar** silkworms belong to the genus *Antheraea* and they are all wild silkworms. There are many varieties such as the Chinese **tasar** silkworm *Antheraea pernyi* Guerin which produces the largest quantity of non–mulberry silk in the world, the Indian **tasar** silkworm *Antheraea mylitte* Dury, next in importance, and the Japanese **tasar** silkworm *Antheraea yamamai* Querin which is peculiar to Japan and produces green silk thread. The Chinese and Japanese **tasar** worms feed on oak leaves and other allied species. The Indian **tasar** worms feeds on leaves of *Terminalia* and several other minor host plants. The worms are either uni- or bivoltine and their cocoons like the mulberry silkworm cocoons can be reeled into raw silk.

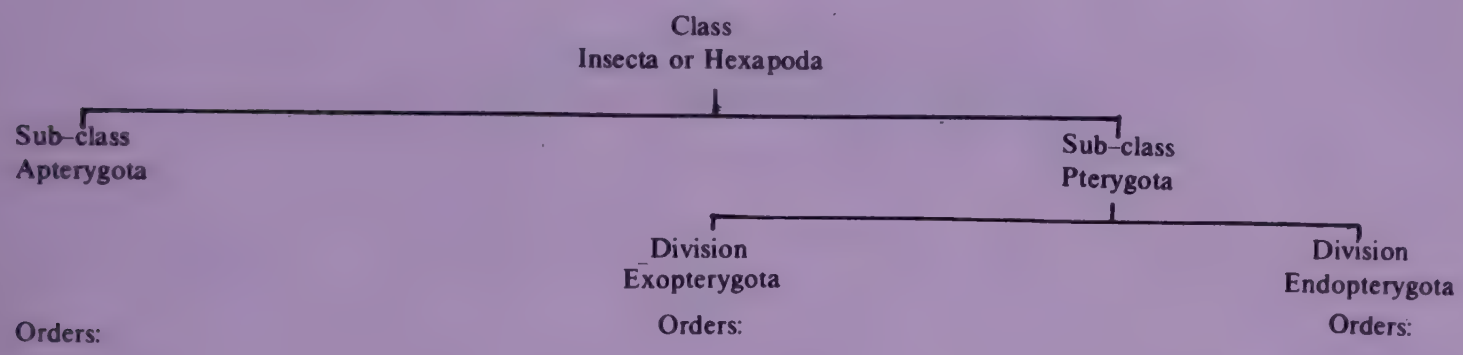
Muga silkworms:

'The **muga** silkworms (*Antheraea assama*) also belong to the same genus as **tasar** worms, but produce an unusual golden–yellow silk thread which is very attractive and strong. These are found only in the state of Assam and feed on som (*Machilus bombycina*) and soalu (*Litsaea polyantha*) leaves and those of other species. The quantity of **muga** silk produced is quite small and is mostly used in the state of Assam itself.

Besides the commercially important silkworm varieties mentioned above, there is also a special silkworm species (*Eriogyna pyretorum* Westwood) which is reared mainly on Hainan Island and used for gut in fishing. These worms feed on leaves of *Liquidambar formosana* Hance.

(ii) Taxonomic classification of silkworms

Silkworms belong to the class *Insecta,* phylum Arthropoda, which comprise by far the largest number of animals of the world. The insects are characterized by the division of the body into three distinct regions namely head, thorax and abdomen. They are segmented in their body structure, a typical insect having six segments in the head, three in the thorax and eleven in the abdomen. They may or may not carry jointed appendages and also one or two pairs of membraneous wings. The class *Insecta* is divided into two sub–classes namely Apterygota and Pterygota and are further divided into divisions and orders as shown below:



1) Thysanura
2) Diplura
3) Protura
4) Collembola

5) Ephemeroptera
6) Odonata
7) Plecoptera
8) Grylloblattodea
9) Orthoptera
10) Phasmida
11) Dermaptera
12) Embioptera
13) Dictyoptera
14) Isoptera
15) Zoraptera
16) Psocoptera
17) Mallophaga
18) Siphunculata
19) Hemiptera
20) Thysanoptera

21) Neuroptera
22) Mecoptera
23) Lepidoptera
24) Trichoptera
25) Diptera
26) Siphonaptera
27) Hymenoptera
28) Coleoptera
29) Strepsiptera

The order Lepidoptera includes all the insects known as moths and butterflies, including the silkworm moth. The different kinds of silkworms fall under the super family *Bombycoidea* which are characterized by the following distinguishing features (according to Imms):

Maxillary palpi and tympanal organs absent. Fraenulum almost always atrophied or vestigial: proboscis rarely developed. Chaetosema absent. Antennae pectinated,especially in male($u_2$absent from both wings: hind wing with Sc and R_1 usually diverging from cell and Rs, or only connected with cell by a cross–vein (R_1).

Bombycoidea comprises eight families of which two namely *Bombycidae* and *Saturniidae* are economically important since some of the members of these families produce natural silk of commercial value as shown below:

Bombycoidea

i) *Bombyx mori*	— the cultivated silkworm.
ii) *Bombyx mandarina*	— the wild ancestor of the commercially cultivated silkworm.

Saturniidae

i) Antheraea pernyi	— The Chinese **tasar** silkworm
ii) *Antheraea mylitta*	— The Indian **tasar** silkworm.
iii) *Antheraea yamamai*	— The Japanese **tasar** silkworm.
iv) *Antheraea assama*	— The Indian **muga** silkworm
v) *Philosamia ricini*	— The **eri** silkworm
vi) *Philosamia cynthia*	— A wild species of the **eri** silkworm
vii) *Eriogyna pyretorum*	— Fish–line silkworm of Hainan Island.

(iii) Morphology

Silkworms pass through a complete metamorphasis (Holometabola) from egg to the adult stage through two intermediate stages of larva (caterpillar) and pupa (cocoon).

The morphology, anatomy and physiology of the silkworm in its different life–cycle stages are discussed below:

Eggs

The silkworm eggs are tiny and weigh around 2 000 eggs to a gramme. They measure 1 to 1.3 mm in length and 0.9 to 1.2 mm in width. The eggs of the European races are comparatively larger and heavier. They may be ovoid, flat, ellipsoid or oval and flat with a micropyle at the anterior pole and slightly off–centre. Races producing white cocoons lay pale yellow eggs while races producing yellow cocoons lay deep yellow eggs. In both cases the Japanese races lay slightly darker eggs than the Chinese races.

In the case of the hibernating eggs laid by bivoltine and univoltine races, the egg colour changes and becomes dark brown or purple with the deepening of the colour of the serosal pigments.

Larva (Fig. 1)

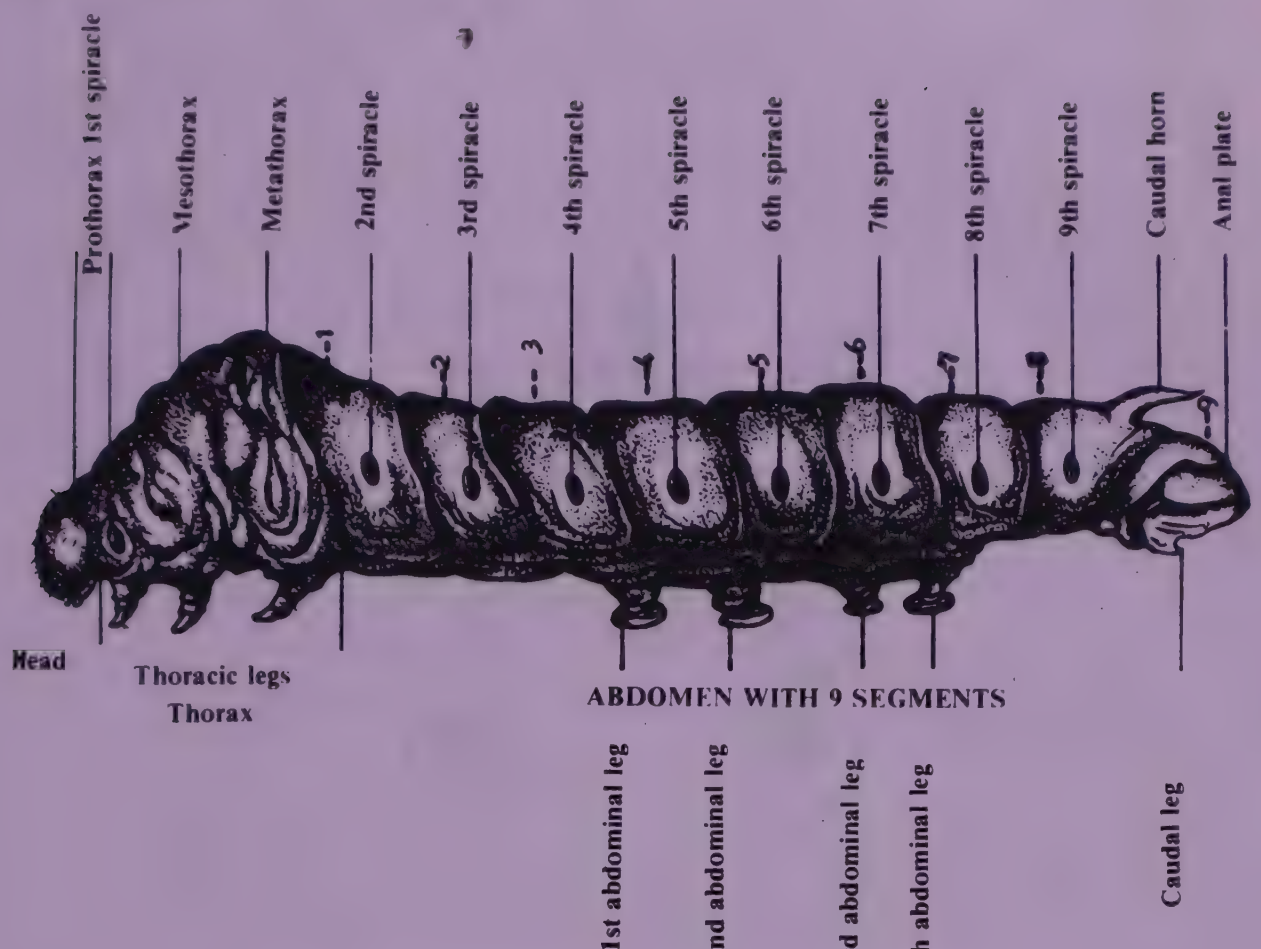


Fig. 1 — Morphology of silkworm larva

The silkworm larva when newly hatched is black or dark brown. It has a large head and the body is densely covered with bristles so that it looks like a hairy caterpillar. There are four pairs of tubercles; the subdorsal, supra spiracular, infra spiracular and basal tubercle each of which carries three to six setae. As the larva grows, it becomes smoother and lighter in colour due to the rapid stretching of the cuticular skin during the different instars of the larval stage. The larval body is composed of the same segments as any insect: head, thorax and abdomen. The entire body is covered with a thin and elastic chitinous cuticle which is capable of being extended considerably to permit rapid growth of the larva during any instar. The integument consists of the epidermis and the cuticle over it.

Head: The head consist of six body segments fused together with a cranium. The second, fourth, fifth and sixth segments carry appendages which are modified into antennae, mandibles, maxillae and labium respectively. Median epicranial suture is well developed and prominent. Similarly on the outer side, the clypeus and the labrum are also prominent. There are six pairs of ocelli or larval eyes which are located behind and a little above the base of the antennae. There is a pair of antennae formed of five jointed segments and these are used as sensory organs (feelers). The mandibles are well developed and powerful and are adapted for mastication (Fig. 2).

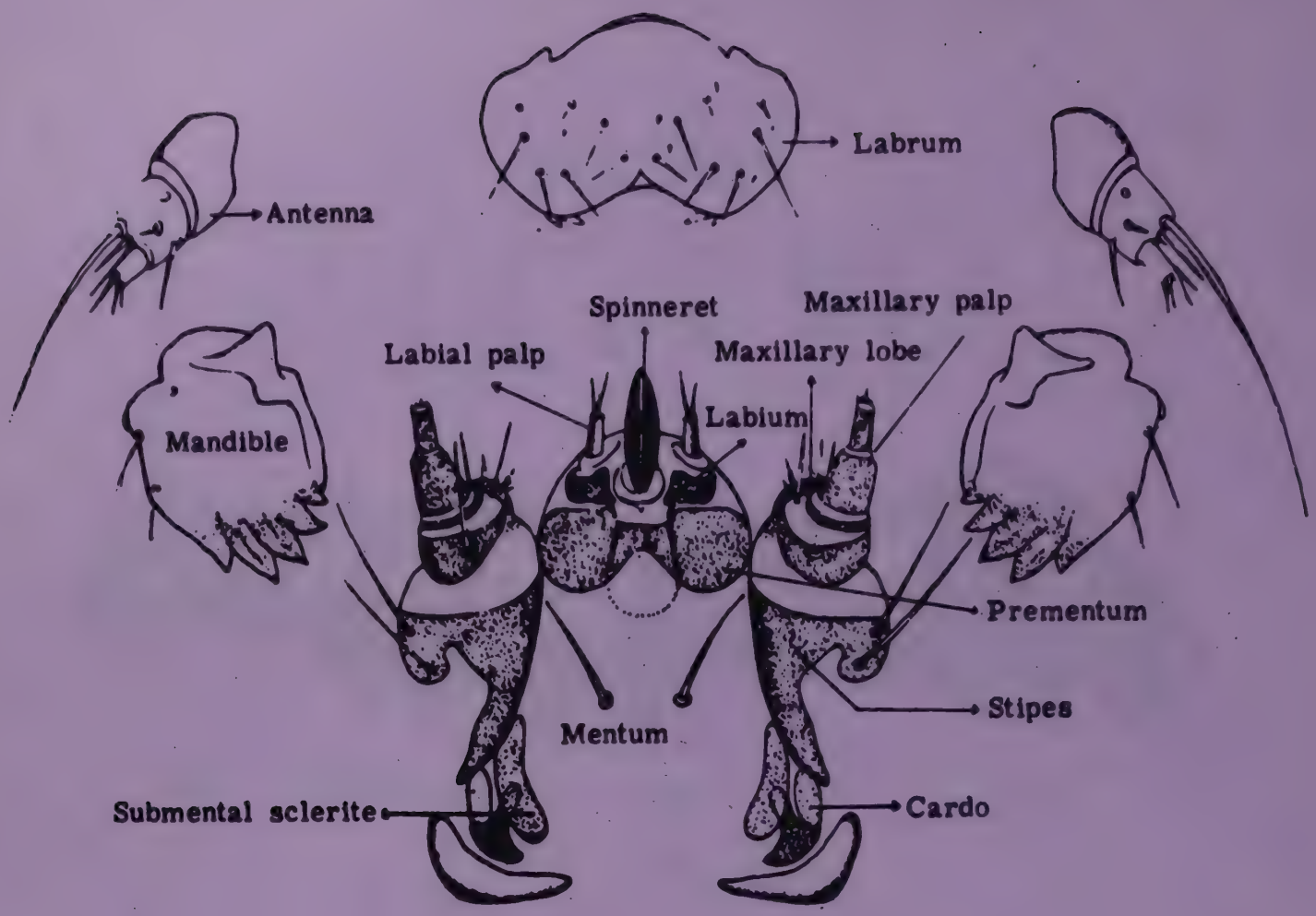


Fig. 2 — Mouth parts of silkworm larva

The maxillae on the ventral side of the mouth, consist of cardo, stipes, maxillary lobe and maxillary palpi. Maxillary lobe and maxillary palpi discriminate the taste of food. The labium is located ventrally carrying a big-sized, lightly chitinized mentum. The prementum is chitinized and black. Distally the prementum carries a median process or spinneret through which silk is expelled from the silk gland to form the silk bave or thread. The sensory labial palpi are found on both sides of the spinneret.

Thorax: The thorax consists of three body segments called the pro-meso-and meta-thorax. Each of the three thoracic segments carries ventrally a pair of legs each comprising in turn three jointed segments. These are the true legs which are conical in shape and carry sharp distal claws. These claws are not used for crawling but for holding mulberry leaves while feeding.

All the silkworm larvae that show body larval markings carry the so-called eye spot on the dorsal side of the meso-thorax.

Abdomen: The abdomen is comprised of eleven body segments although only nine can be distinguished as the last three are fused together to form the apparent ninth segment, the anal plate and the caudal legs. The third to sixth and the last abdominal segments each bear a pair of abdominal legs which are fleshy, unjointed muscular protuberances. At the extremity they form a sort of disc with a series of hooks inwardly curved and arranged in a semicircle. On the dorsal side of the eighth abdominal segment, the larva carries the caudal horn.

The abdominal segments carry the sexual markings which develop distinctly in the fourth and fifth instars in the eighth and ninth segments on the ventral side (Fig. 3)

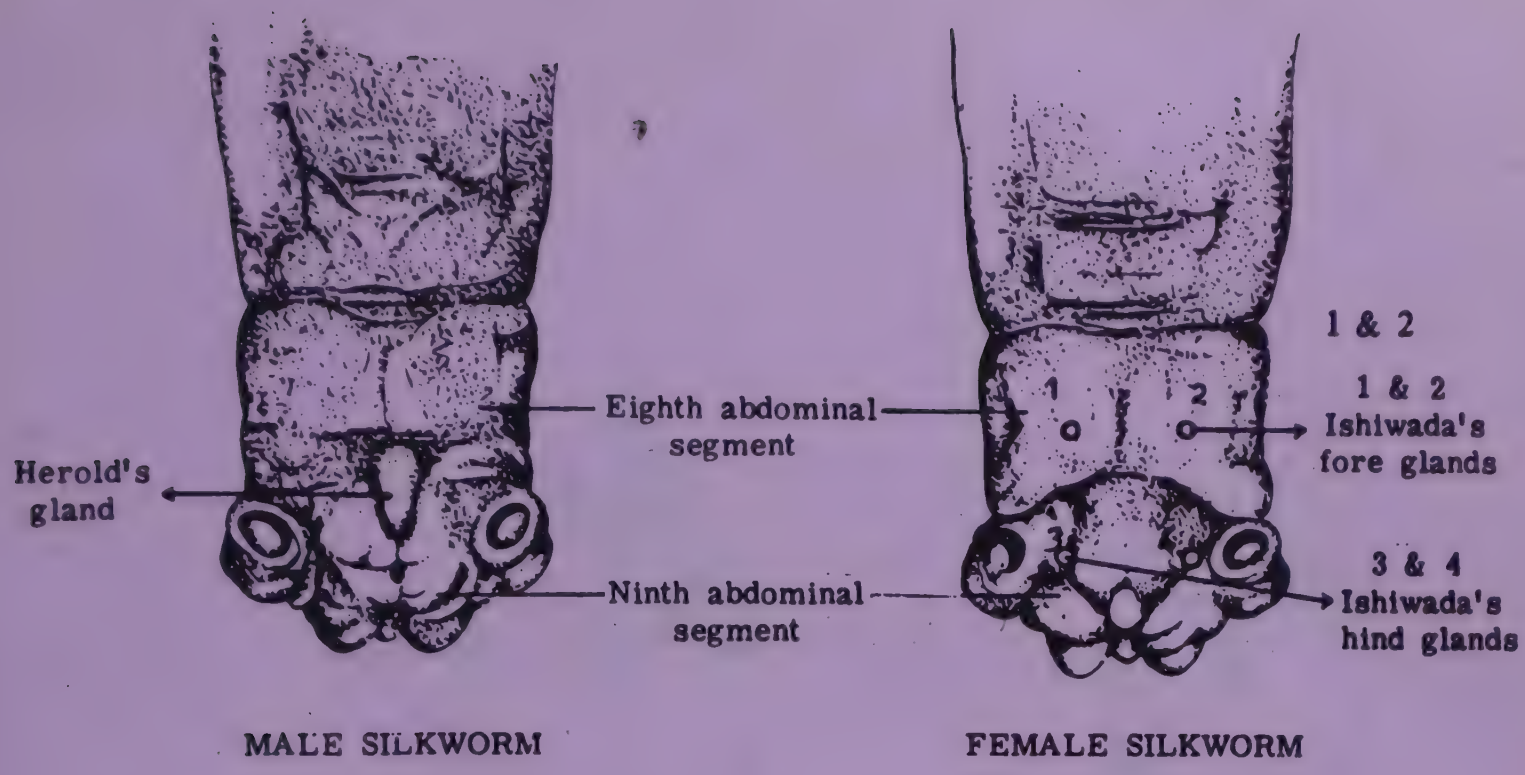


Fig. 3 — Posterior abdominal segments of male and female silkworm larva

In the female the sexual markings appear as a pair of milky white spots in each of the eighth and ninth segments.The pair of spots on the eighth segments is known as Ishiwata's fore glands and the pair on the ninth segment is referred as Ishiwata's hind glands. In the male a small milky white body (Herold's gland) appears at the centre of the ventral side between the eighth and ninth segments.There are in all nine pairs of spiracles placed laterally on either side of the body. They are found on the first thoracic segment and the first eighth abdominal segments.These are the breathing or respiration pores.

The larval skin or integument consists of the cuticle and the hypodermis. The cuticle is made of chitin as well as protein and is covered with a thin layer of wax. Nodules are found all over the body surface of the silkworm larva. The distribution of these nodules differs according to the vareity of silkworms, being less in number in varieties having lustrous body surfaces, such as the Chinese bivoltine and the multivoltine varieties. The nodules are found in larger numbers over parts of the body where normally the larval markings are found. The larval markings in silkworms are caused by skin pigment.

Pupa: The pupal stage is generally called the resting, inactive stage of the silkworm when it is incapable of feeding and appears quiescent. This is a misnomer. The pupal stage is a transitional phase during which definite changes take place. During this period of biological activity the larval body and its internal organs undergo a complete change and assume the new form of the adult moth. The mature silkworm larva passes through a short transitory stage of pre-pupa before becoming a pupa. During the pre-pupal stage the dissolution of the larval organs takes place and this is followed by the formation of adult organs during the pupal stage. Soon after pupation the pupa is white in colour and soft but gradually turns brown to dark brown and the pupal skin becomes harder.

The prominent morphological parts visible are a pair of large compound eyes, a pair of large antennae, fore–and hind–wings and the legs. Ten of the abdominal segments can be seen on the ventral side, but only nine of them are visible on the dorsal side. Seven pairs of spiracles can also be discerned in the abdomen; the last pair is non–functional. Sex markings are prominent and it is much easier to determine sex in the pupal stage than in the larval stage. The female has a fine longitudinal line on the eighth abdominal segment, whereas such a marking is absent in the case of the male (Figs. 4,5).

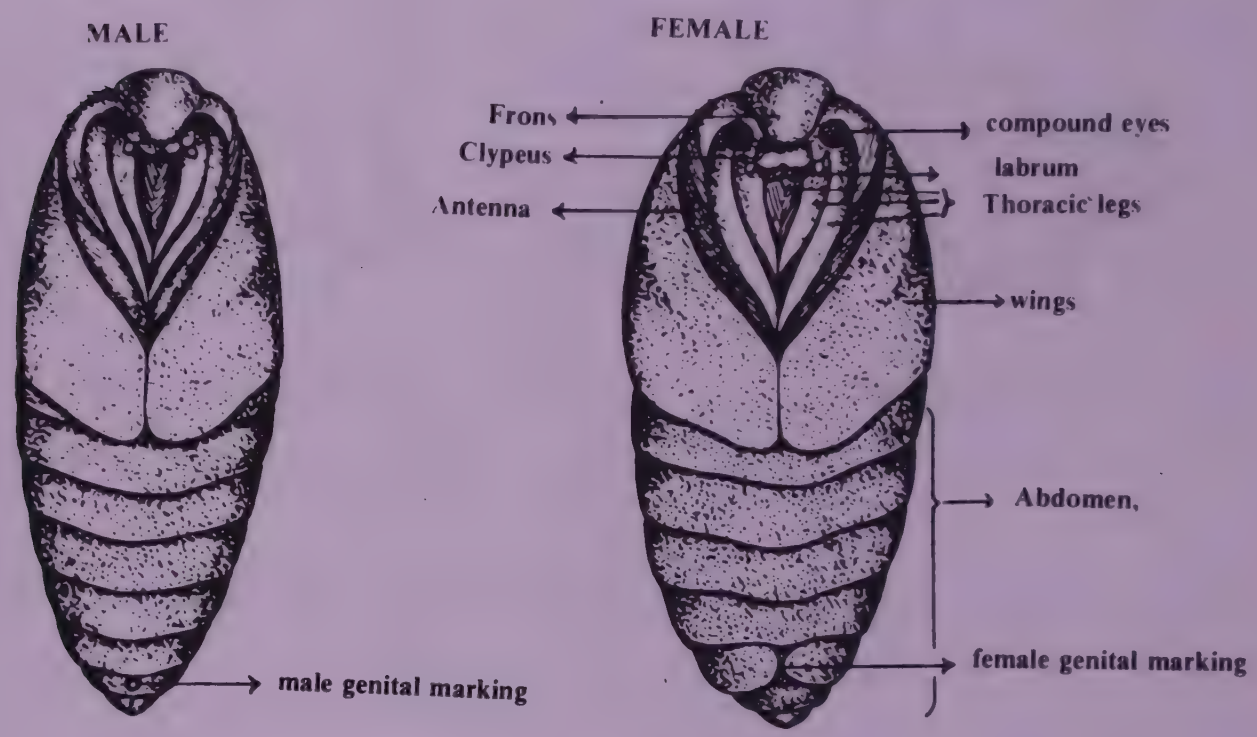


Fig. 4 — Drawing of male and female pupa *Bombyx mori*

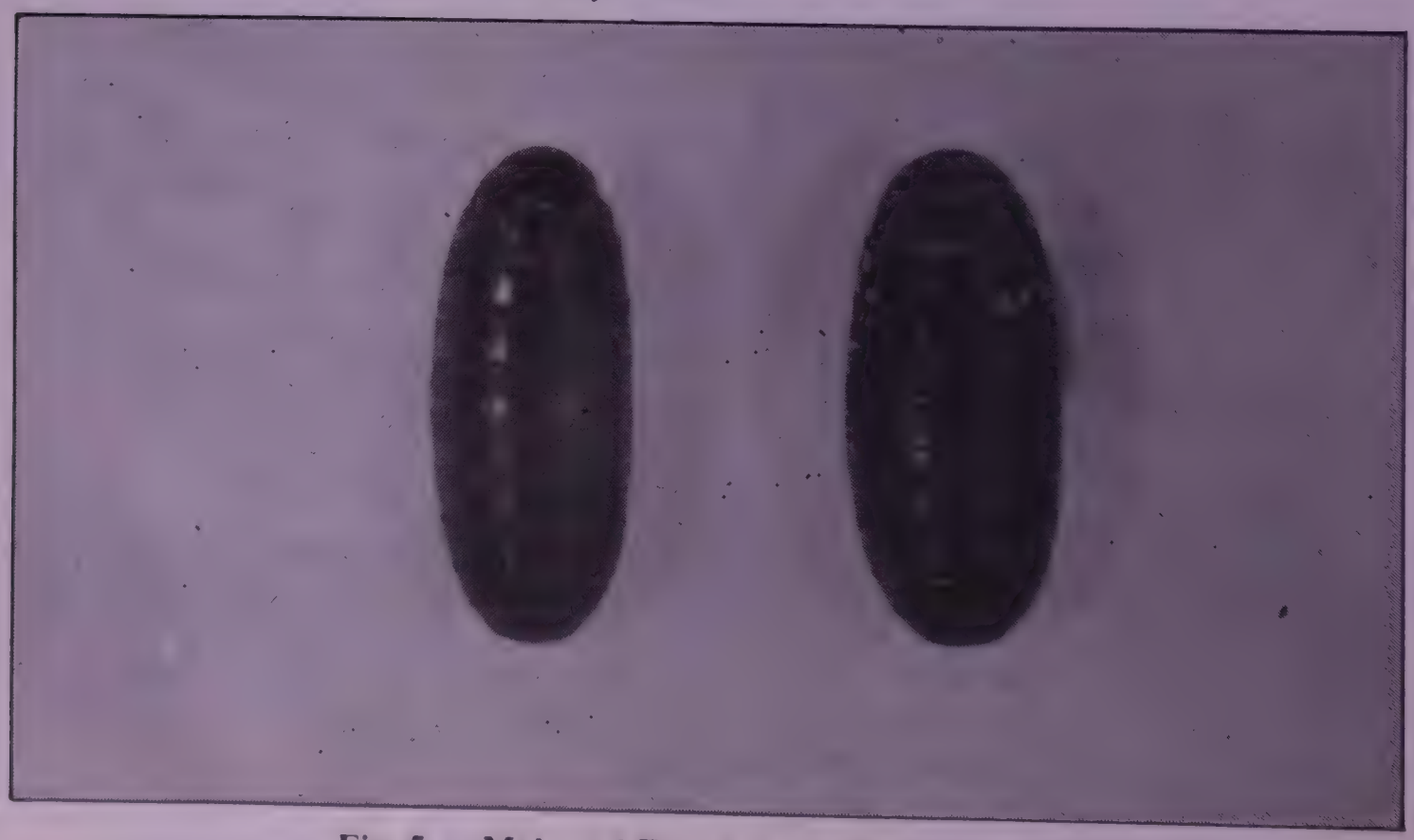


Fig. 5 — Male and Female pupa *Bombyx mori*

Adult: The adult moth emerging from the pupa is incapable of flight as a result of its domestication for more than four thousand years. It does not feed during its short adult life. The body of the moth like that of the larva is composed of three distinct segments: head, thorax and abdomen. Another important characteristic in common with other moths and butterfiles is that the body surface is covered with scales. The compound eyes are situated on either side of the head. The ocelli are absent. The antennae are conspicious, large and bi-pectinate.

The thorax consists of three segments namely pro-, meso-and meta-thorax as in the larva. The meso thorax is the largest and is pentagonal. There are three pairs of thoracic legs, one pair on each of the three thoragic segments. Each of the thorasic legs is composed of five segments. The meso- and meta-thorax bear two pairs of wings, the front pair overlapping the hind pair when the moth is in the resting position.

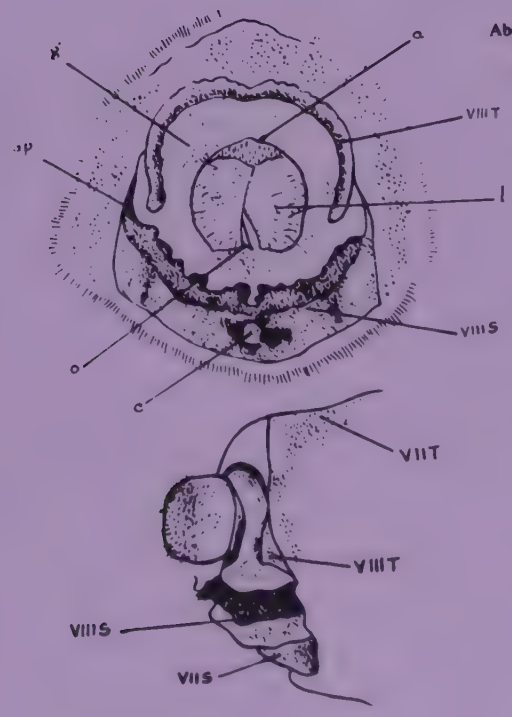
In the male eight abdominal segments are visible; in the female seven. There are six pairs of spiracles present laterally on either side of the body.

Morphologically the female and male can be easily distinguished in the adult stage. The female has comparatively smaller antennae, its body and the abdomen are fatter and larger and it is generally less active than the male moth. At the caudal end, the male moth has a pair of hooks known as harpes (Fig. 6) where as the female moth has a knob-like projection with sensory hairs. (Fig. 7). These differences help to a large extent in separating the sexes for preparation of hybrid eggs.

1) CLASPERS (HARPES or HOOKS)

2) AEDEAGUS

Fig. 6 — Abdominal end of male moth



Abdominal end of female moth

(Rear view)

a) Anus
ap) Apophysis
c) Ostium bursae (copulatory opening)
R) Sacculi laterals
l) Labin
O) Oviporus

(lateral view)

VII T & VIII T-7 & 8 Abdominal tergite
VII & VIII S — 7 & 8 Abdominal sternites

Fig. 7 — Abdominal end of female moth

v) Anatomy and physiology
Digestive system

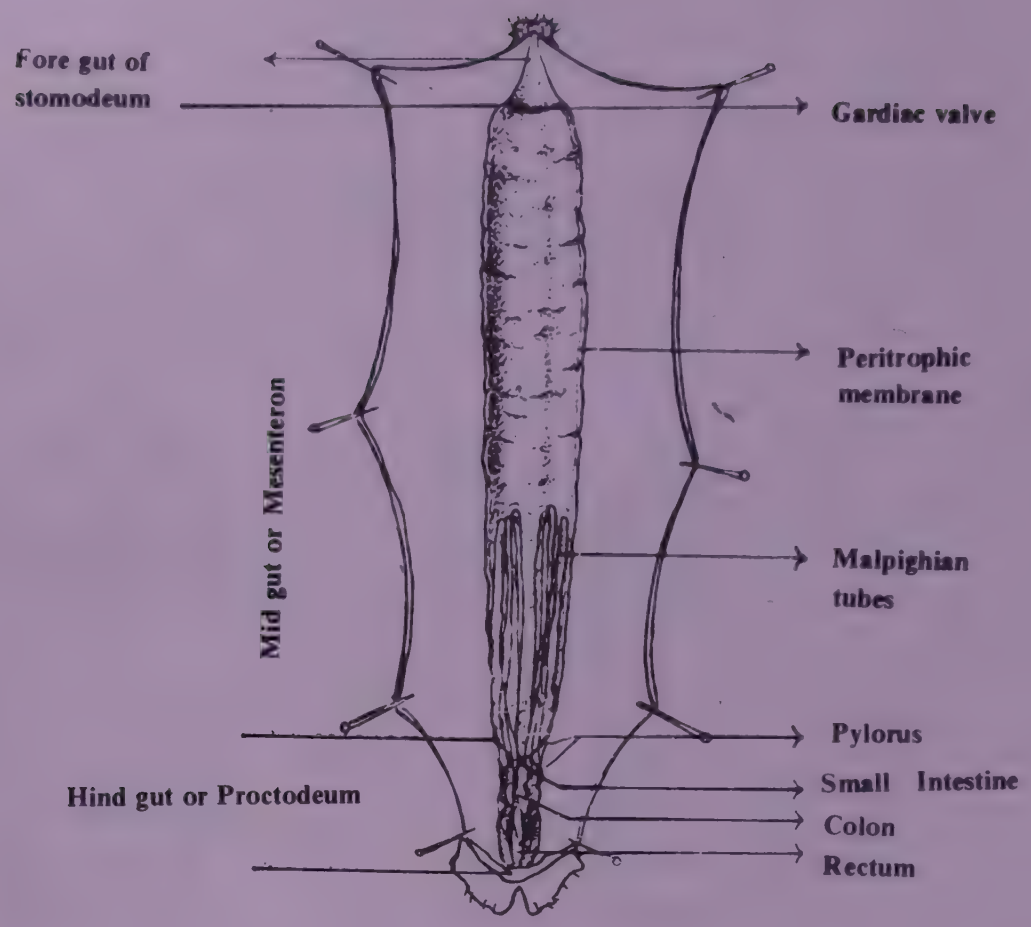


Fig. 8 — Digestive system of silkworm larva

In the silkworm larva the digestive system is more or less a straight tube from the mouth to the anus divided into three main parts: the fore-gut or stomodeum, mid-gut or mesenteron, and hind-gut or proctodeum. The oral aperature opens into the mouth cavity which is followed by a narrow pharynx and oesophagus. The oesophagus is narrow at the anterior end and gradually widens towards the posterior end. There is a cardiac or stomodeal valve at the end of the fore-gut that retains the chewed mulberry leaf bits in the oesophagus for sometime and also prevents the regurgitation of food from mid-gut to fore-gut. The mid-gut is a long, wide cylindrical tube narrow at the posterior end. Digestion and assimilation of food, take place mainly in the mid-gut. The digestive fluid is secreted principally from the goblet cells at the mid-gut epithelium and the cylindrical cells absorb the digested food. The fore and hind guts have a chitinous lining, but an inner layer of peritropic membrane in the mid-gut generally protects the mid-gut epithelium from mechanical damage due to food particles. The hind-gut consists of the small intestine, colon and rectum, and a pylorus valve near the anterior end of the small intestine which guards and regulates the passage of digested food from the mid-gut to the hind-gut. The hind gut is a passage for the absorption of a large portion of food moisture and elimination of digested food. In the anterio-posterior direction, the rectum has six muscles for pressing the excrements. The faecal matter is pressed in the rectum and expelled from the anus as faecal pellets bearing haxagonal marks.

In the adult the probosis is vegtigial as well as non-functional and the adult does not feed. Hence the adult digestive system appears degenerated and less prominent than the larval digestic system. The alimentary tract is formed of a long oesophagus of narrow calibre with a diverticulum attached to the oesophagus by a short tube, followed by a tubular stomach, hind-intestine and rectal sac. The

diverticulum (sucking stomach) of the fore-intestine appears to be a main receptacle for the air that is swallowed and distends the body after metamorphosis. Since the adult takes no food this may be its main function. A couple of delivery glands open into the oesophagus. Six Malpighian tubes are present, three arising from each side of the hind-gut by a common tube. The hind intestine enlarges into a rectal sac and ends in the anus by a short tube.

Excretory system

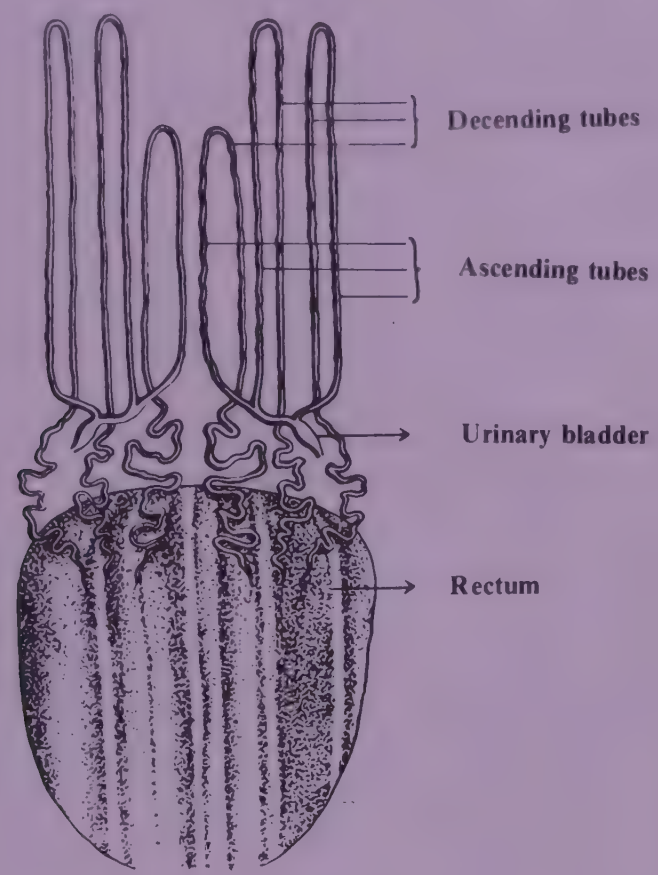


Fig. 9 — Excretory system of silkworm larva

The Malpighian tubes are the primary organs of excretion. In the larva the Malpighian tubes arise at the junction of small intestine and colon in the hind-gut of the digestive tract. The tube arising on each side of the hind-gut is enlarged into an excretory chamber from which two branches arise. One of the tubes situated on the dorsal side branches further into three tubes. In all there are three pairs of Malpighian tubes in the silkworm larva that stick to the midgut and run towards the anterior side, turn back and ultimately open into the rectum. Nitrogeneous compounds like protein are metabilised by these tubes and excreted principally as uric acid. They also excrete calcium oxalate. The Malphigian tubes in the mature larve are light yellow and their walls contain large quantities of yellow vitamin B_2.

Respiratory system

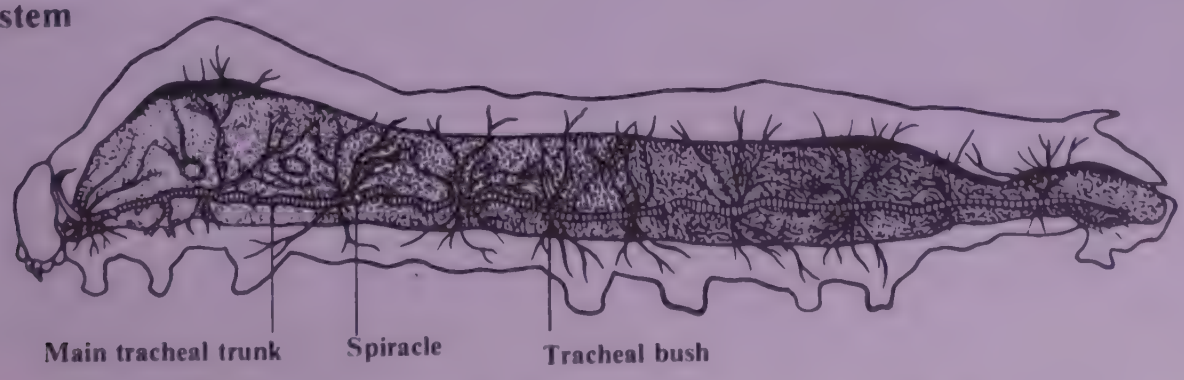


Fig. 10 — Respiratory system of silkworm larva

Respiratory system

The respiratory function is carried out through the spiracles by the movements of the body wall. In the larva there are nine pairs of spiracles, one on each side of the pro–thorax from the first to the eighth abdominal segments. Peritreme, sieve plate and atrium are the parts of the spiracles. The peritreme forms a ring round the spiracle. A slit can be seen along the median line of the sieve plate inside the ring. The external opening of the spiracle leads into a cavity, the antrium which contains the closing apparatus. There are two closing membranes and their movement can be observed if the sieve plate is taken off. The sieve plate prevents the entry of dust and air. A number of tracheal branches start radially from the spiraclar cavity. There are also two large tracheas called main or lateral tracheal trunks connecting all the tracheal bushes. The ventral transverse tracheas connect the two tracheal bushes in each segment. The trachea ramify repeatedly throughout the body and organs and ultimately form tracheoles. When the diameter of the tracheae is reduced to one micron, these finer tubules are called tracheoles and they carry oxygen directly to the cells and tissues. Through such a network of tracheae and tracheoles oxygen is carried to the various parts, tissues and cells of the body and carbon dioxide is removed, through the same channels. The terminus of each tracheole is a single cell and the oxygen supply is diffused from the tracheoles to the cells.

Tracehae are similar in structure to the integument and also consist of a supporting thickened ring–like structure called the *taenidium* which keeps the tubes distended and prevents them from collapsing.

Circulatory system

The circulatory system is an open one with a dorsal vessel, extending from the head to the last abdominal segment along the dorsal median line of the body. The dorsal vessel is associated with the circulation of the blood and is closed posteriorly while the front end opens in the head. The anterior portion of the dorsal vessel is a finely drawn–out tube and constitutes the aorta, while the posterior portion forms the heart. Each of the segments from the second thorax to the ninth abdominal segment contains a pair of ostia. There are eight pairs of alary muscles which are attached to the body wall along the lateral parts of the dorsum. Systole (contraction) and diastole (expansion) of the heart are effected by the eight pairs of alary muscles and the musculature of the heart. The alary muscles function more or less like an elastic band and cause diastole and systole.

The blood enters the heart mainly through the ostia in the seventh and eighth abdominal segments and to a slight extent only through the ostia in the first six abdominal segments during diastole, and is forced forward during systole. As the heart is filled with blood, a steady wave of contraction progresses in a posterior — anterior direction. Hence normally the direction of flow of blood in the dorsal vessel is from behind forward and the blood is carried to the head and discharged. It leaves the dorsal vessel not only by the anterior end but also by the ostia in the meso and meta–thorax and sometimes by the ostia in the first and second abdominal segments. The blood flows backward through the body cavity. There is nothing to prevent the blood leaving the ostia, and the blood circulates throughout the body cavities and appendages transporting nutrients and removing waste products of the metabolism, and filling most of the space not occupied by the internal organs. In the silkworm, the blood cells or haemocytes do not enter the dorsal vessel through the ostia. Only cell–free plasma is circulated. The heart pulsates rhythmically and the frequency of pulsation varies with age, temperature, movements and the race of the larvae.

In the pupa the ostia have posterior valve flaps only and the backward flow of blood is not restricted; entering blood goes forward or backwards.

In the adult the dorsal vessel occupies a more or less similar position as in the larva but for a deflection extending up to the dorsal wall at the junction of the abdomen and thorax in the form of a loop. The loop is enlarged and is called the aortal chamber.

Blood or haemolymph

The blood or haemolymph consists of plasma and corpuscles or haemocytes such as proleucocytes, plasmocytes. microcytes, macronucleocytes, spheroidocytes and oenocytoids. Haemocytes play an important role in the defence mechanism against micro-organisms and in the encapsulation of foreign bodies. Proteins, aminoacids, salts and large amount of water are also present in the blood. The pH of the blood is approximately 6.3 to 6.5 and the specific gravity is 1.02 to 1.04. The main enzymes of blood are tyrosinase, amylase, and catalase. Races of silkworms that spin white cocoons have pale yellow blood, whereas races that spin coloured cocoons may have pale to deep yellow blood. Pigmentation of the blood is due to the xanthophyll in the mulberry leaf. The respiratory function of the blood is insignificant and mainly serves as a medium of transport for nutrients, hormones and metabolites.

Muscular system

In the silkworm larva the muscles are of the striated type. They control various movements, e.g. of the head for spinning, of the mandibles for masticating leaves, of the abdominal legs for crawling and so on. The body is formed by a combination of muscles attached to the endoskeleton. The head muscles consist of cervical muscles, muscles of the mouth parts and muscles of the antennae each controlling the movements of the respective parts. Head movements are controlled by the cervical muscles: levator, depressor, retractor and rotator. The muscles of the mouth parts are the levator, depressor, flexor (adductor) and extensor (abductor) muscles.

Pleural muscles, and muscles attached to the thorax form the wing muscles in adults. The longitudinal, dorso-ventral and the pleural muscles are found in the meso and meta-thorax. Here as in the abdomen there are three kinds of muscles. Leg muscles consist of flexor and extensor muscles. In adults, there are very few muscles in the head but the thoracic muscles are well developed. The abdominal muscles in the copulatory apparatus are different in males and females.

Nervous system

Central nervous system

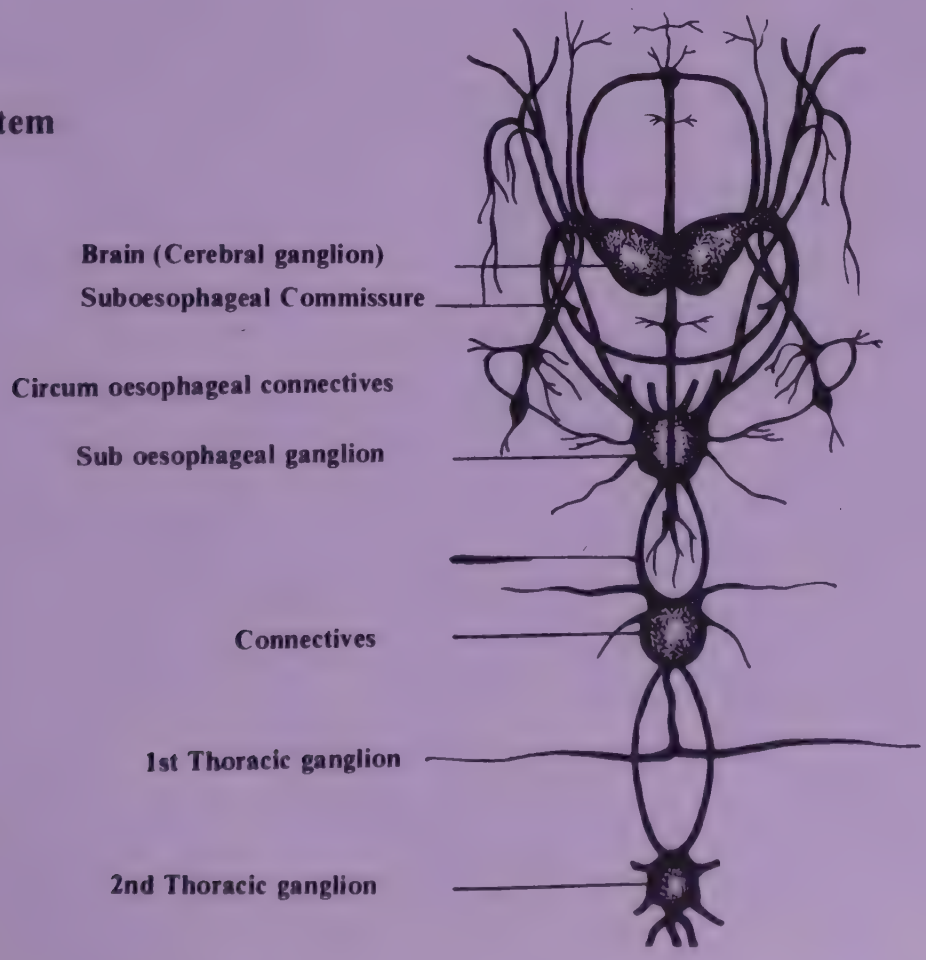


Fig. 11 — Central nervous system of silkworm larva

The central nervous system of the silkworm larva is divided into the brain or supraoesophageal (cerebral) ganglion, the suboesophageal ganglion and the ventral nerve cord. The brain lies in the head, dorsal to the oesophagus and consists of two pear-shaped lobules. It is formed by the protocerebrum, deutocerebrum and tritocerebrum and is the dorsal ganglionic centre of the head. In the larval stages, the three regions of the brain are not marked externally. The brain innervates the ocelli of the larva, antennae and labmum. The ganglia of the mandibular, maxillary and labial segments have coalesced to form the suboesophageal ganglion which is the ventral ganglionic centre of the head and is connected with the brain by a pair of circum-oesophageal connectives that runs around either side of the oesophagus. the suboesophageal commissure arises from the circum-oesophageal connectives, very near to the origin of the latter from the brain. The suboesophageal ganglion of the larva innervates the mandibles, maxillae and labium with paired nerves.

Typically in insects the central nervous system consists of a double series of ganglia but the members of a pair are usually so closely fused that they appear to be a single ganglion.

In the silkworm larva the ventral nerve cord is formed by a series of ganglia on the floor of the thorax and abdomen below the alimentary canal. These are connected in a longitudinal chain by paired connectives arising from the posterior end of the suboesophageal ganglion. The thorax consists of three ganglia, one in each thoracic segments, and eight ganglia in the abdmen, one each in the first to the eighth abdominal segment. From each thoracic ganglion two pairs of principal nerves arise of which one pair innervates the general musculature and the other pair innervates the leg muscles. Each abdominal ganglion has a pair of principal nerves that innervate the muscles of the corresponding segment.

In the silk moth the brain and the suboesophageal ganglion are fused together into a mass ringing the oesophagus. In the adult, the optic lobes are massive and occupy a large area of the cranium, whereas in the larva the optic lobes are not developed and only two long optic nerves arise from the brain.

An additional third pair of nerves, in the second and third thoracic segments, innervates the wings and controls the fluttering movements. The ventral nerve cord is formed by three thoracic ganglia located close together (the meso-and methathoracic ganglia are almost fused) and four abdominal ganglia, the latter being located far from the metathoracic ganglion. The last abdominal ganglion is composite.

Visceral or sympathetic nervous system

The visceral or sympathetic nervous system is formed by a oesophageal sympathetic and a ventral sympathetic system. The oesophageal sympathetic system is directly connected with the brain innervating the fore and mid-gut, dorsal vessel and other parts. It consists of a median triangular frontal ganglion above the ooesophagus in front of the brain and is connected to the brain by bilateral connectives. The frontal ganglion has anteriorly a frontal nerve which goes to the clypeus, and posteriorly a median recurrent nerve which travels along the mid-dorsal side of the oesophagus and ventrally to the brain for some distance, meets the hypocerebral ganglion, extends from there and ends in the ventricular or stomachic ganglion toward the rear end of the oesophagus. From here the adjacent regions of the fore and mid-gut are innervated.

The ventral sympathetic nervous system is formed by a pair of transverse nerves linked with the ventral nerve cord ganglia. A median longitudinal nerve connects each pair of transverse nerves with the preceding ganglion. The transverse nerves innervate the spiracles of the corresponding segment.

The caudal sympathetic system innervates the reproductive system and the posterior portion of the gut and consists of nerves emerging from the composite (the last) ganglion of the abdomen.

Peripheral sensory nervous system

It is fine network of sensory bipolar neurones which have connections with the sensory hairs and the central nervous system, and multipolar neurones which make an elaborate plexus beneath the integument. The multipolar neurones have distal connections branching on the surface they supply and centripetal connection to the central nervous system ganglia.

Reproductive system

In the larva, the sexual phase develops in the late instars when it may be possible to note in the female, a pair of triangular ovaries (gonads) situated on the dorsal side of the sixth abdominal segment; from each of which a blind tube arises and terminates at the eighth abdominal segment.The pair of translucent spots seen ventrally on the eighth abdominal segment is the Ishiwata's foreglands and the pair on the ninth abdominal segment is the Ishiwata's hind–glands. These four ventral spots are prominent in the fifth instar and are used to identify the female larva.

The male larva consists of a pair of kidney–shaped testes (gonads) on the dorsal side of the fifth abdominal segment and a blind tube which is connected with the Herold's gland — a milky white body — at the centre of the ventral side between the eighth and ninth abdominal segments.

In the female moth, paired ovaries occupy most of the abdominal space (Fig. 12).

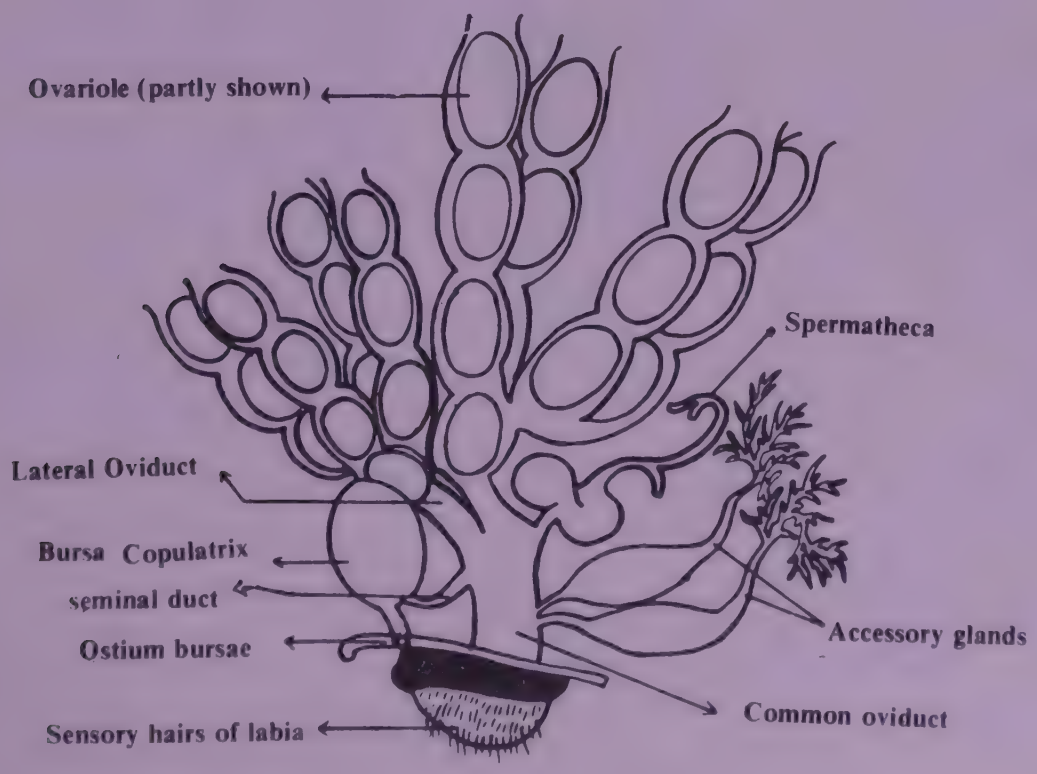


Fig. 12 — Reproductive system of female moth

A pair of lateral oviducts arises from the ovaries and unites to form a single, wide common oviduct that ends in the oviporus at the posterior end of the body. Each of the ovaries carries four egg tubes or ovarioles where the eggs are formed. The ovarioles are polytrophic and an alternating succession of nurse cells and oocytes (developing eggs) are found in the egg chambers particularly in the pupal stage. In the adult stage, the four pairs of ovarioles look like coiled strings of beads containing eggs. The *bursa copulatrix* is a sac–like structure situated ventrally to the common oviduct and continues as a tube to the outside posteriorly on the eighth abdominal segment. At the time of mating, the *aedeagus* is received by the opening, *ostium bursae,* of this tube. The *bursa copulatrix* also opens into the common oviduct by a narrow tube known as the seminal duct. Paired accessory glands occur dorsally to the common oviduct. The accessory glands produce an adhesive material which coats the eggs when they pass down the common oviduct and glues them to the substratum when they are laid. The spermatheca is a sac–like structure for the reception and storage of spermatozoa and opens into the common oviduct anterior to the accessory glands opening.

In male moth a testis is present in the fifth abdominal segment dorso–laterally on each side of the ventral nerve cord. (Fig. 13). The *vas efferens* of each testis leads into a *vas deferens* which opens into the seminal vescicle from where an ejaculatory duct arises and ends in the *aedeagus.* A pair of accessory glands open into the seminal vesicle by a common duct located between the two *vasa deferentia.* The membranous sac or the spermatophore is formed by the secretion of male accessory glands.

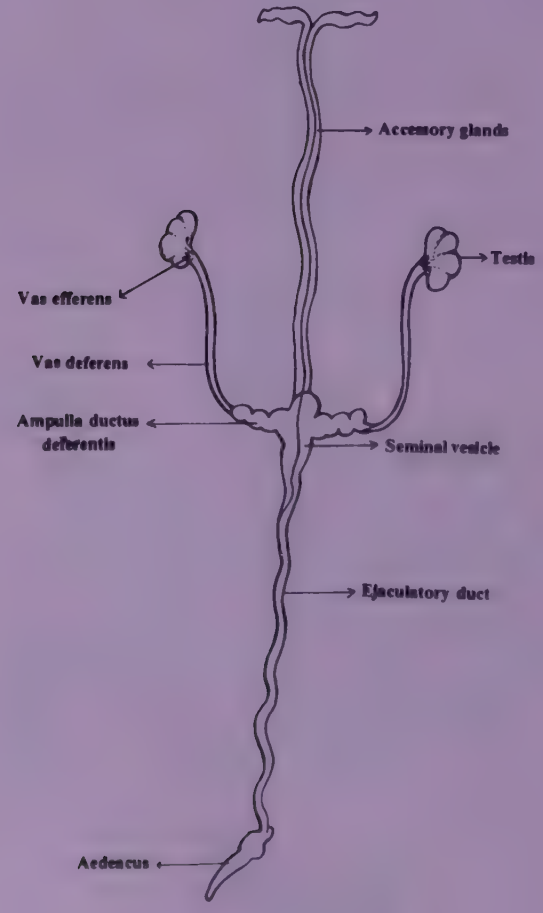


Fig. 13 — Reproductive system of male moth

Glands

Exuvial glands

These are specially enlarged hypodermal cells which secrete a fluid that facilitates the process of ecdysis or moulting.

Salivary or mandibular glands

These open near the articulations of the mandibles and are paired. They are filamentous tubular glands, blind posteriorly and they secrete saliva.

Silk glands

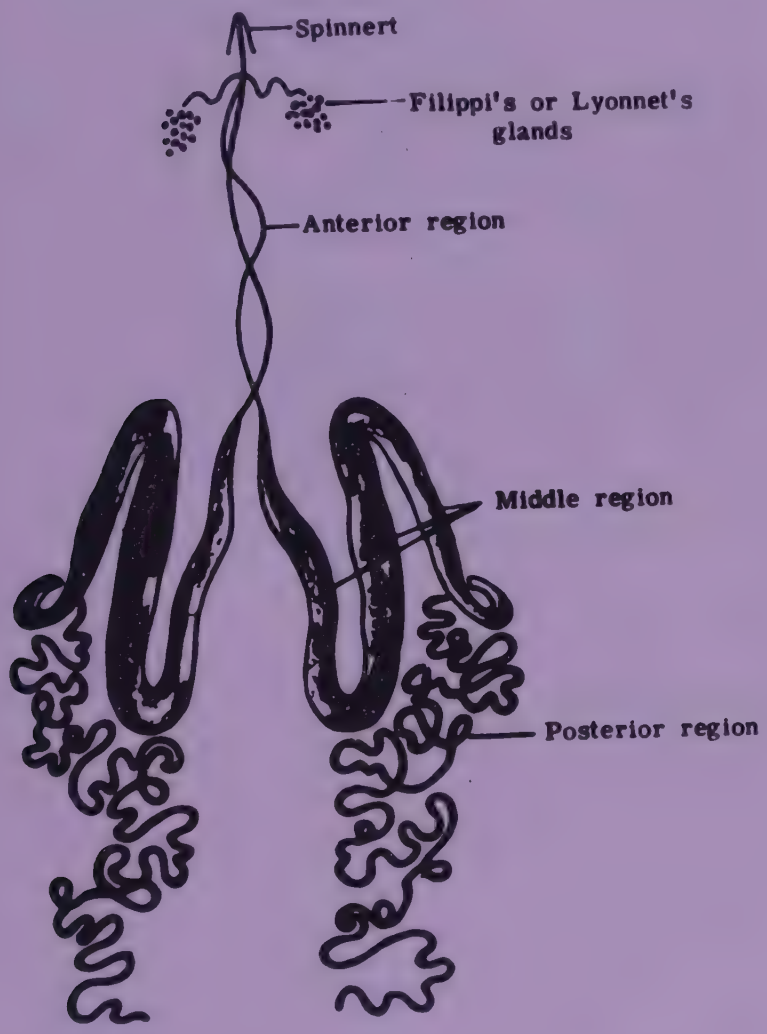


Fig. 14 — Silk glands of silkworm larva

These are transformed labial glands, ectodermal in origin, cylindrical and tubular with characteristically branched nuclei. They are situated on the ventro–lateral sides of the mid–intestine and the posterior ends are blind. Anteriorly, the paired ducts unite and open into the spinneret. Silk glands may be divided into three distinct regions; anterior, middle and posterior. The anterior region is a straight tube opening at the fore end into the duct and posteriorly into the middle region.

The middle region is the largest of the three regions and has three definite flexions. The middle region is again divided into three functionally different sections: anterior, middle and posterior. The beginning of the middle region is narrow but widens suddenly — the middle part is the widest and the end of the rear part is narrow. The posterior region is crooked and curved between the dermo-viseral muscles and the tracheae.

A pair of glands known as Filippi's or Lyonnet's glands is situated at the junction of the two anterior regions. A viscous fluid is secreted by these glands and their exact function is not clear.

The wall of the silk gland is composed of three layers, the *tunica propria,* the gland cells, and the *tunica intima* enclosing the lumen of the gland. The *tunica intima* is made up of thickly laid chitin throughout but the anterior portions are renewed at each ecdysis or moult.

Fibrion and sericin are secreted in the fourth and fifth ages. Fibrion, the silk protein, is secreted from the posterior region. The middle region acts as a reservoir for the maturation of fibroin and also secretes sericin around the fibroin as below. Sericin I, the innermost sericin, is secreted from the posterior section of the middle region; sericin II, the middle-layered sericin, from the middle section of the middle region; sericin III, the outermost sericin from the anterior section of the middle region. The anterior region of the silk gland does not secrete any particular substance; it is simply a passage and carries the silk substance from the reservoir (middle region) for freezing.

Prothoracic gland

It is a T-shaped glandular body of internal secretion, consisting of a bead-like string of cells, situated on the inner side of the first thoracic spiracle of each side close to the main tracheal trunk. This gland releases a secretion into the blood known as ecdyson or moulting hormone that is responsible for the initiation of moulting in larval stages and of pupation. The pupal prothoracic gland secretes a substance repsonsible for the initiation of imaginal or adult characters.

Suboesophageal ganglion

This is a ganglion of the central nervous system and is situated on the mid-ventral aspect of the oesophagus. The suboesophageal ganglion has a number of neurosecretory cells larger than 25 microns in diameter. The diapause factor, which is responsible for the diapause nature of silkworm eggs, is secreted from the neurosecretory cells in the suboesophageal ganglion during the pupal stage of the mother moth.

Peritracheal gland and cells

These are associated with the pericardium, and the secretions help in the digestion of protein substances in the body fluid and in cleaning the blood.

Corpora allata (Fig. 15)

These are a pair of small avoid, whitish, glandular bodies lying behind the brain and closely associated with the *corpora cardica*. *Corpus allatum* produces the juvenile hormons that inhibits pupation and keeps the larva in the larval stage. In the absence of the secretions from the *corpora allata*, the moulting larvae would undergo precocious pupation.

Neurosecretory cells of the brain (Fig. 16)

The neurosecretory cells of the brain are the source of the activation hormone. They are arranged in two groups placed symmetrically on the upper surface of each hemisphere near the median furrow in the *parsintercerebralis protecerebri* of the brain.

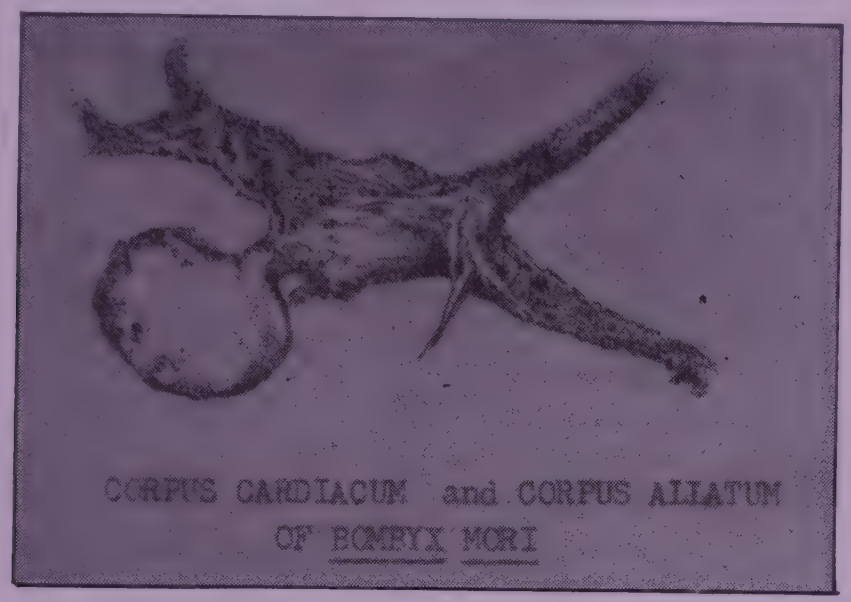


Fig. 15 — *Corpus cardiacum* and *corpus allatum* of silkworm larva

These are bluish white nerve cells that have acquired a secretory function. The secretion liberated from these cells flows along two pathways: (i) from the neurosecretory cells into the *corpus cardiacum* and then into the *corpus allatum;* and (ii) from the brain to the blood through the cortex of the brain. The activation hormone does not induce moulting directly but activates the prothoracic glands to secrete ecdyson.

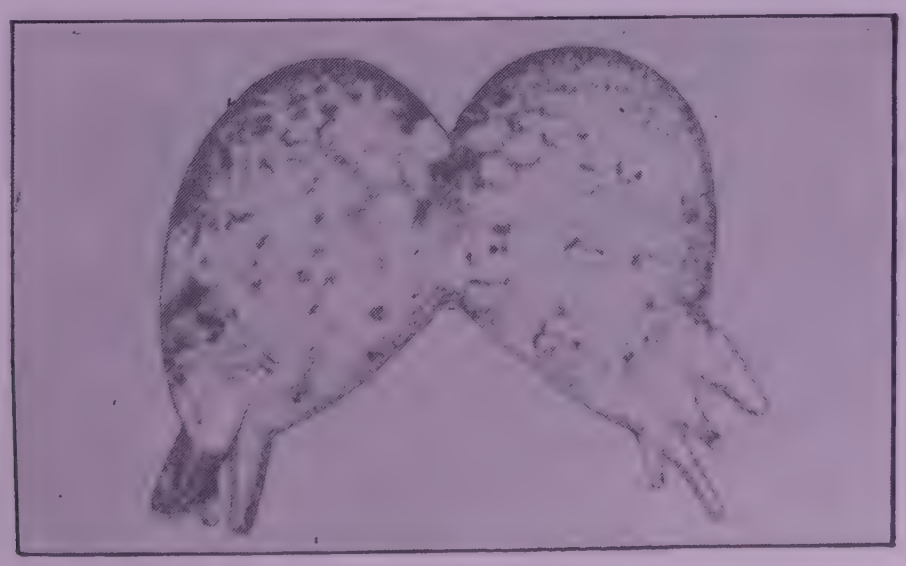


Fig. 16 — Neurosecretory cells of the brain of silkworm larva

Corpora cardiaca (Fig. 15)

A pair of bodies behind the brain in front of the *corpora allata*. They are connected with the neurosecretory cells of the brain through the *nervi corporis cardiaci* with the *corpora allata* by the *nervi corporis allati*. The secretory material originating in the brain is seen both in *corpora cardiaca* and *corpora allata*.

Male and female accessory glands

As already mentioned above these glands are connected with the reproductive system.

Scent glands

Scent glands are well developed in members of the Bombycidae family in which the eggs are fully developed or oviposition at the time of emergence. It has been found that the sex attractant (pheromone) is produced from the paired lateral glands, *sacculi laterales,* of the last abdominal segment of the virgin, receptive female moths for attracting the male moths for copulation.

The receptive female moth controls the release of the sex attractant by protruding and retracting these glands. After mating, the female produces hardly any sex attractant. The sex attractant in *Bombyx mori* is sensed by the male moth through the olfactory receptors of the antennae.

(v) Biology

Life cycle

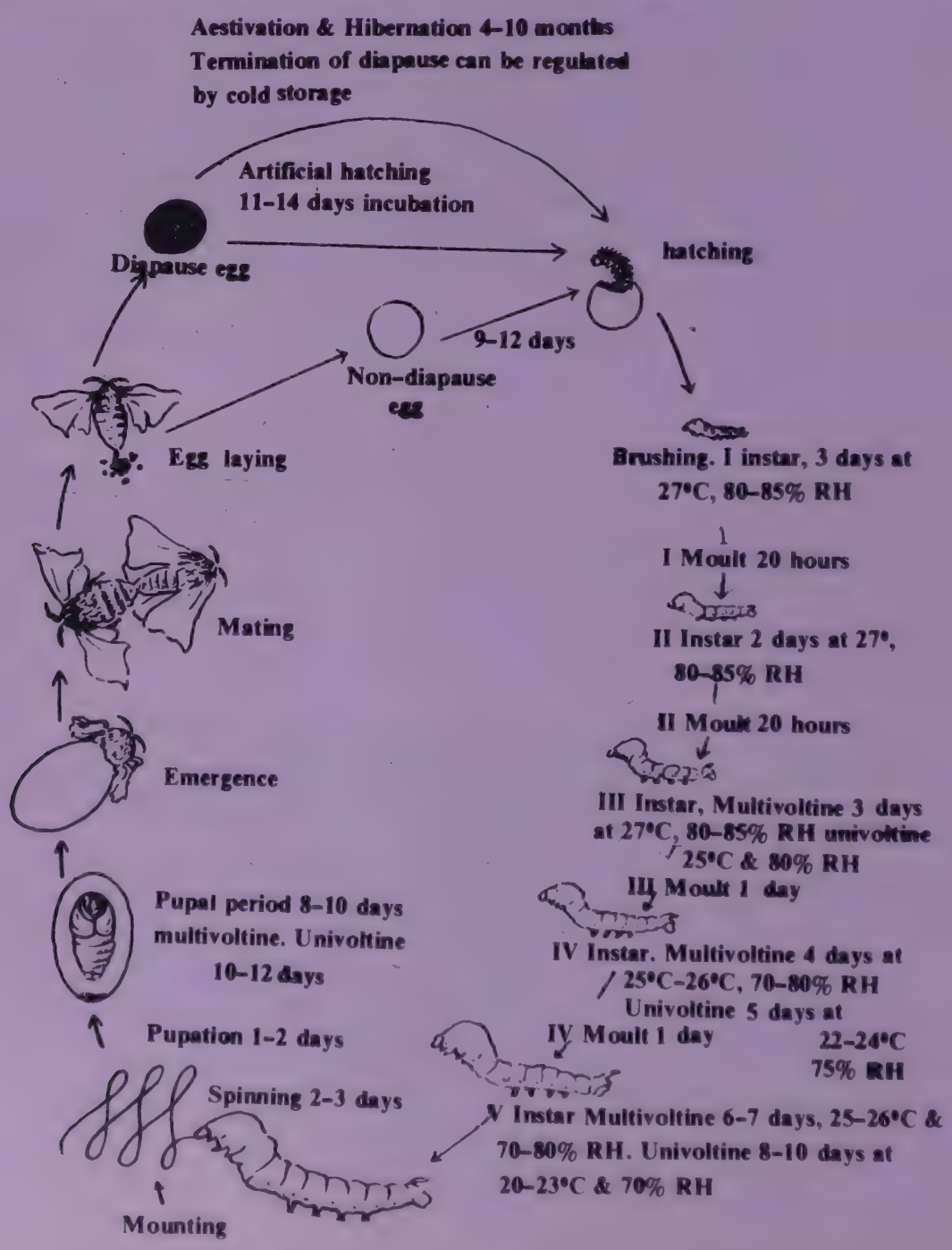


Figure 17 — Life cycle of silkworm

As in the case of a typical Lepidopteran insect, the silkworm passes through four distinct stages, i.e., egg, larva, pupa and adult during its life cycle, the duration of which may last for six to eight weeks depending upon racial characteristics and climatic conditions. Multivoltine races found in tropical areas have the shortest life cycle with the egg, larval, pupal and adult stages lasting for 9–12 days, 20–24 days, 10–12 days and 3–6 days respectively. In univoltine races, the egg period of the activated egg may last for 11–14 days, the larval period 24–28 days, the pupal period 12–15 days and the adult stage 6–10 days.

In nature the univoltine races produce only one generation during the spring, and the second generation egg goes through a period of rest or hibernation till the next spring. In the case of the bivoltine races, however, the second generation egg does not hibernate and hatches within 11–12 days and produces the second generation normally during summer. But it is the third generation egg which undergoes hibernation and hatches only the next spring, thus producing only two generations in a year (bivoltine). In multivoltine races, the life cycle is the shortest because of the warmer ecological conditions where they are reared, and so they may yield as many as seven to eight generations in a year in tropical sericultural areas such as India, Thailand, etc. Silkworm rearing is, therefore, continuous in tropical areas whereas in sub–tropical and temperate zones it is mostly seasonal lasting from spring to early autum.

Larval life

In sericulture it is the larval life that is of direct importance to the rearer since he has to tend the worms very carefully. The larval life may last from 20–24 days in the case of the multivoltine species in tropical areas or 24–28 days in the case of uni and bivoltine races in temperate areas, being shorter under warmer summer and autumn conditions, and some what longer under cooler spring conditions. During the larval life the worm moults or casts off its skin four times to be able so as to grow. There are also varieties of worms which moult three and five times but they are not of importance economically.

In view of the four intervening moults, the larval life is divided into five distinct stages or instars which are referred to popularly as five different ages. The first three instars are referred to as "young ages" and the fourth and fifth instars as "late ages". The duration of the different instars and moulting periods for the different races is as follows:

Duration of different instars and moulting periods

		Multivoltine races		Uni and bivoltine races	
			Temperature and humidity conditions		Temperature and humidity conditions
I	instar	3 days		3 days	
I	moult	20 hours		20 hours	
II	instar	2 days	27°C	2 days	27°C and 85% R.H.
II	moult	20 hours	80–85% R.H.	20 hours	
III	instar	3 days		3 days	25°C and 30% R.H.
III	moult	1 day		1 day	
IV	instar	4 days	25–26°C	5 days	22–24°C and 75% R.H.
IV	moult	1 day	70–80% R.H.	1 day	
V	instar	6–7 days	"	9–10 days	20–23°C and 70% R.H.
		22–23 days		26–27 days	

Moulting

Each larval instar can be broadly divided into two phases: the feeding phase and the moulting phase. After feeding voraciously and having attained full growth for the particular instar the worm loses its appetite and the larva prepares to moult and cast off its old skin. Prior to each moulting, the larva stops feeding and rests with its head held up. The lustrous body skin gradually becomes translucent, loose and wrinkled and the worm becomes dull in appearance and wanders about in search of a resting place. It emits a silky substance with which it fixes itself to dry leaves.

The moulting periods last for 15–30 hours being shortest in the second moult, followed by the first, third and fourth. This resting for moulting is often referred to as "going to sleep" and the coming out of the worm from moult as "waking up". During the moulting period the worms should not be disturbed so that the process of moulting is not interfered with and uniform moulting is ensured.

Mature worms

After the silkworm passes through four moults, it reaches the fifth and final instar when it attains its maximum weight a day prior to maturity and before it stops feeding. At its maximum weight it is about 10000 times its won weight at the time of hatching and this phenomenal growth takes place within the short span of 20–25 days. When the worm is fully mature for mounting, it loses it appetite, stops feeding, and excretes soft faeces with high moisture content. At this stage because of its voluminous increase in size, the silk gland is visible through the body integument and, therefore, the thorax and body segments of the mature larva appear translucent. In fact the silk glands are so enlarged as to account for nearly 40 per cent of the body itself. This is characteristic of the ripened worm and serves as guidance for picking the mature worms for mounting. The mature worms become very restless and raise their heads insearch of support so as to be able to start spinning.

Spinning of the cocoon

The spinning of the cocoon starts almost immediately after mounting and in 48–72 hours spinning is completed by the mature worm. In another day or two the worm transforms itself into the pupa within the cocoon.

The pupal period may last for 8–14 days after which the adult moth emerges slitting through the pupal skin, and piercing the fibrous cocoon shell with the aid of the alkaline salivary secretion that softens the tough cocoon shell.

The adult moths are ready to copulate immediately after emerging from the pupa and the female then lays the eggs. Adult life is short, lasting from 3–10 days depending upon races and seasons. The adults do not feed and are also incapable of flight having lost the faculty owing to domestication over thousands of years. The females are larger in size and generally sluggish while the males are somewhat smaller and more active. A female of the multivoltine variety may lay an average approximately 400 eggs while the average number for the uni–and bivoltine varieties of silkworm moths is from 500–600.

(vi) Gametogenesis and embryonic development

Slightly off the median line of the ventral plate of the silkworm are the primordial germ cells which give rise to the gonads or reproductive tissues which ultimately form the testes in the males and the ovaries in the females.

Spermatogenesis

Each testis is divided into four follicles and at the blind end of each follicle a single giant, apical cell is found. This cell is also known as Verson's cell and is the supporting and nourishing cell of the young germ cells. Also near the blind end of each testicular follicle is a mass of primordial germ cells surrounding the apical cell. Three days after hatching, the primary and secondary spermatogonia are differentiated. The number of spermatogonium in the testicular follicles increases by division as the silkworm grows. In about the middle of the fifth instar of the larval period, the spermatogonia in the testes divide actively and produce numberous spermatognia surrounding the Verson's cell. The spermatogonia after division increase in size, are called spermatocytes and are found enclosed in a membranous cover in groups of approximately 64. After undergoing two reduction divisions, the spermatids become slender spermatozoa by transformation at the time of larval mounting for cocoon spinning.

Spermatozoa

Dimorphism in the spermatozoa is distinguished in the silkworm. The normal nucleoated spermatozoa are known as eupyrene spermatozoa and the non-nucleoated spermatozoa are referred as apyrene spermatozoa. The difference between the two is in the location and the shape of the nucleus. The apyrene spermatozoa are said to be incapable of fertilization. Under natural conditions the apyrene spermatozoa are absorbed near the end of the testicular follicles. A nucleoated sperm consists of a long filamentous body with an acrosome followed by the chromatic head, axial filament, sheath substance and the tail. There is one nutritive cell near the head.

Oogenesis

In the young stage of the silkworm larva, each of the two female gonads is partitioned into four compartments. During the course of development, they elongate, become tubular and form four ovarioles or ovarian tubules on each side of the ovary. At the proximal end of each ovariole a spindle-shaped apical cell can be distinguished. Below the apical cell a mass of cogonia is observed, which multiply very rapidly by direct division and move downward toward the distal end of the ovarioles. They stop division at a certain stage and form into groups of eight cells each. Of the eight cells one develops into an oocyte and the remaining seven differentiate into nurse cells or trophocytes. These cell groups arrange themselves in a row in the ovarioles and the oocyte is always at the lower portion of the nurse-cell group.

The nucleus, which at first is located at the centre of the oocyte, moves to the upper side of the cell. Nurse cells and oocyte are enclosed by common follicular epithelium and are separated into an egg chamber and a nutritive chamber. The nurse cells are irregular in appearance and become smaller during the development of the oocyte through supplying yolk substances. The oocyte continues to grow and later becomes the egg, while the nurse cells degenerate completely. When the nurse cells are fully absorbed, thick follicular cells envelop the developing egg and supply nutrients to it. Later when the egg cell is fully grown, the follicular cells secrete the chorion or egg shell around the egg and the egg is formed. The egg cell is much larger than the spermatozoan and is mostly made up of yolk, which is rich in fat and protein. The reduction division in the case of the silkworm is not completed until after one to two hours of oviposition. In the formation of the egg cell, three of the four nuclei resulting from reduction division are released leaving one in the egg to become its nucleus. When the reduction division is complete the chromosome number is reduced by half.

Structure of silkworm egg

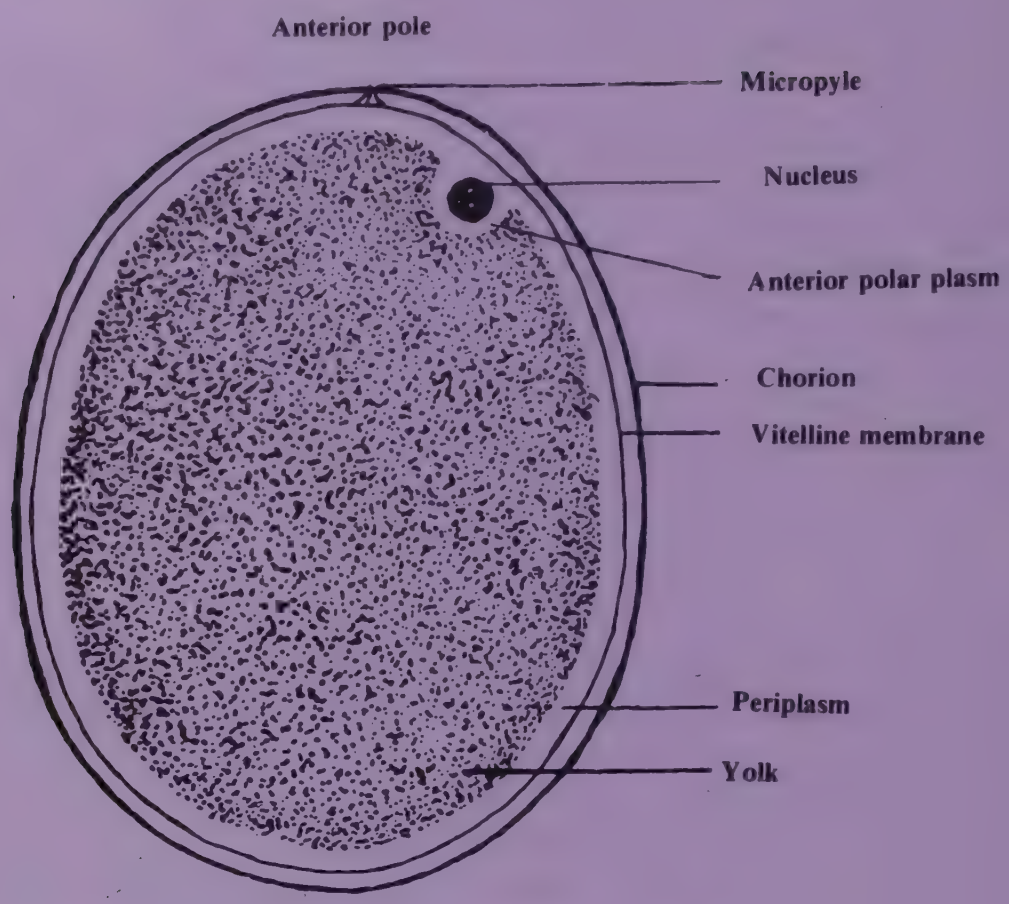


Fig. 18 — Structure of silkworm egg

There is only one micropyle at the anterior pole. Soon after entrance the microphyle branches into three small canals which reach the inside of the chorion. The sperm enters through the micropyle. The respiratory canals are funnel–shaped tubes which become smaller as they go inward. They are distributed in large numbers over the entire surface of the egg except around the micropyle. The air necessary for respiration enters through the respiratory canal and CO_2 is expelled. A thin vitelline membrane is found close to the inside of the chorion. The vitelline membrane covers the protoplasm and the yolk. The yolk is not present throughout the egg but just below the vitelline membrane, a thin layer of cytoplasm does not contain the yolk and this portion is called the periplasm which is particularly thick around the micropyle. This area is called the anterior polarplasm and contains the egg nucleus.

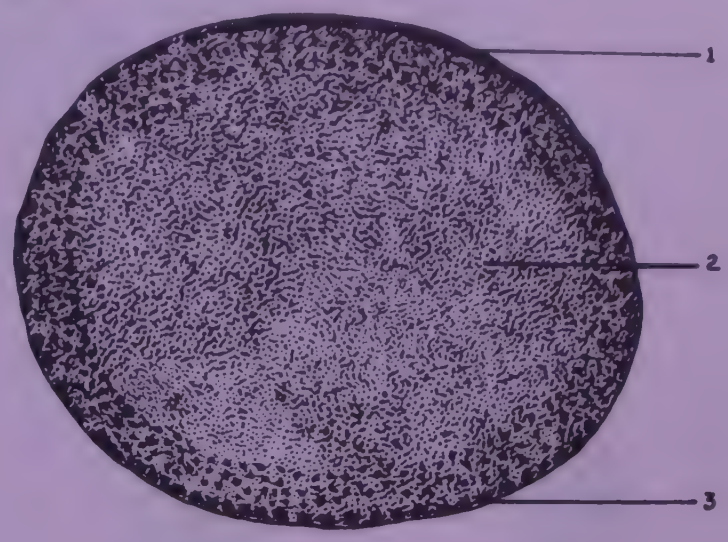
Fertilization

When male and female silk moths copulate, ejaculation occurs and innumerable spermatozoa enter the *bursa copulatrix* in the female reproductive system in the form of spermatophores (bundles of spermatozoa covered by a sheath). The spermatozoa emerge from the spermatophores in the *bursa* and ultimately reach the spermatheca or seminal receptacle. When the eggs pass down the oviduct prior to laying, the spermatozoan moves from the spermatheca to the oviduct and enters the egg through the micropyle, which is situated at the anterior side of the egg. More than one spermatozoa may enter the egg but only one of them can fertilize the ovum; the rest degenerates and disappear.

The spermatozoan entering the egg does not penetrate further but waits at the anterior part of the egg until the maturation divisions of the egg nucleus are completed.

During this interval the sperm sheds its tail, the central body of the sperm divides into two and the anterior part swells into a spherical body — the male pronucleus. Meiosis of the egg nucleus results in the formation of three polar bodies, which migrate toward the vitelline membrane, and one functional nucleus (female pronucleus) with 28 chromosomes. This haploid nucleus now attracts the sperm nucleus which also contains 28 chromosomes and fertilization takes place by fusion forming the zygote, thus restoring the original chromosome number of the organism.

Cleavage and blastoderm formation

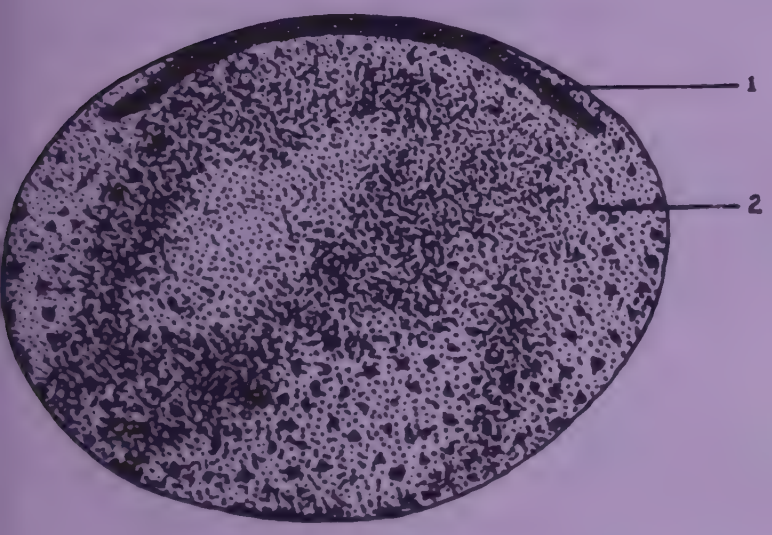


1. Formation of ventral plate
2. yolk
3. Blastoderm cells

Fig. 19 — Egg 16 hours after laying

The zygote undergoes superficial cleavage and divides mitotically to form many nuclei, which become enveloped in a star–like mass of protoplasm. Many of the cleavage nuclei migrate to the periphery and merge in the periplasm forming a band of cells called the blastoderm. Some of the cleavage nucleii do not move to the periphery but remain in the yolk and form yolk cells or vitellophags. Their function is to supply nourishment to the developing blastoderm cells.

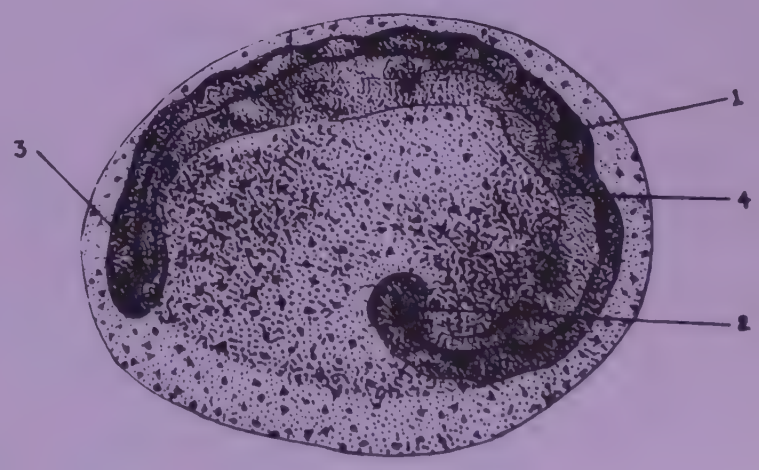
Germ band formation (Figs. 20, 21)



1 Ventral plate

2 Yolk cells (Vitellophags)

Fig. 20 –Egg 1 day after laying

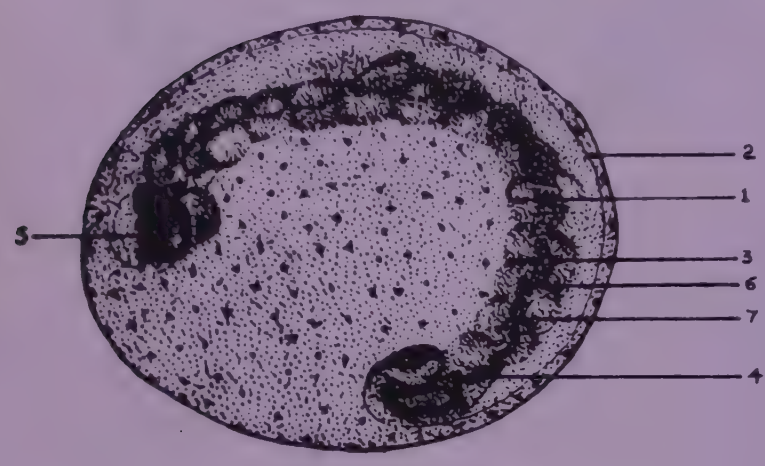


1 Germ band 2 Caudal lobe

3 Cephalic lobe 4 Amnion

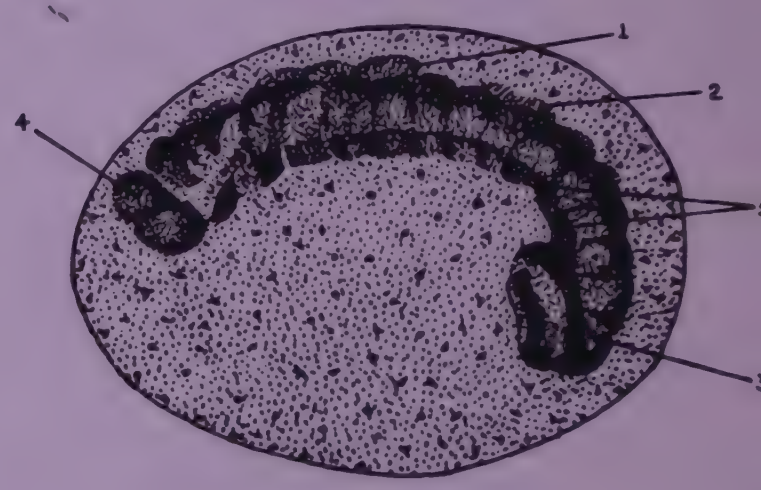
Fig. 21 — Egg 2 days after laying

Part of the cells forming the blastoderm on one side of the egg divide actively and close up together to form the ventral plate which becomes further distinguished as the germ band as the ventral plate becomes thicker. The germ band then develops gradually into a guitar shape and both ends become enlarged. The top end enlargement is called the protocephalic lobe and the tail end expansion is called the caudal lobe. The germ band gradually begins to sink inside while the membranous blastoderm grows from all sides forming a fold to cover the whole surface of the sinking germ band. This fold, consisting of two layers, continues to grow until the layers reach the centre of the germ band. The outer layer forms the seroza which covers the entire surface of the egg and the inner membrane the amnion, which covers the ventral side of the germ band.



1. Amnion
2. Serosa
3. Endoderm cells
4. Hind gut
5. Fore gut
6 & 7. segmental ganglion

Fig. 22 — Egg 3 days after laying



1. Thoracic legs
2. Abdominal legs
3. Hind gut
4. Supraoesophageal ganglion
5. Mid gut

Fig. 23 — Egg 3 days and 16 hours after laying

Along the mid–portion of the germ band on the upper side a long narrow depression called the primitive groove or streak or median plate is formed. Below the primitive groove a new group of spherical cells develop which ultimately give rise to the mesoderm, which can be distinguished from the columnar cells of the original tissue or ectoderm. The ectoderm is the lower layer from which the mesoderm is formed. Some of the median plate cells penetrate deep into the embryo and differentiate to form the endoderm cells later on.

In the case of non–hibernating eggs the development of the embryo proceeds (Fig. 23) and is completed in about ten days; the young larva hatches out from the egg about the tenth day after oviposition. As the primitive groove deepens and the opening is covered by its lips, it gradually becomes a tube and a small aperature, the blastopore, appears in the head. In case of the hibernating or diapause egg, the embryo rests around this stage wihtout much further change till the hibernation period is over. The blastopore is closed during the diapause period. When the diapause period is over, the embryo gradually increases in length till it reaches the maximum length of 75–80 percent of the total circumference of the egg. This stage is called the longest embryo stage. During the maximum length period, the segmentation of the body gradually becomes pronounced.

There are 18 embryonic segments in the silkworm; the first four segments form the head, the next three the thorax and the last eleven segments the abdomen (although in a generalized insect the head consists of six segments).

The longest embryo stage is most important from the point of refrigeration of the eggs. So as to attain uniform hatching the embryo at the longest embroy stage is kept at a low temperature. After being released from cold storage the embryo grows in thickness and gradually becomes shorter and shorter. At this stage, the body segmentations become more prominent with the segmental appendages distincly developed. At the head end four pairs of appendages develop which ultimately become antennae, mandibles, maxillae and labium; the three pairs of thoracic appendages, thoracic legs. From the head and tail end, the ectoderm further grows inward to form tubes which ultimately become fore and hind–guts. The mid–gut is formed from the endoderm. At about this time, the embryo increases in thickness and a line of depression on the ventral ectoderm is formed. The embryo becomes reduced in length and increased in width as the colon saces appear with the development of the mesoderm. The neural furrow occurs along the central line of the ectoderm, and neural ridges arise along both sides of the neural furrow. In addition to the seven pairs of appendages of the head and thorax, eleven pairs of appendages develop on the abdominal segments. Of these, only the third to the sixth and the eleventh abdominal segments develop; the others degenerate and disappear.

Blastokinesis, involution or revolution of the embryo

1. Suboesophageal ganglion
2. Buccal opening
3. Brain
4. Thoracic legs
5. Rectum
6. Segmental ganglion

Fig. 24 — Egg 4 days after laying

1 Brain
2 Suboesophageal ganglion
3 Fore gut
4. Buccal opening
5. Mid gut
6. Hind gut
7. Anus

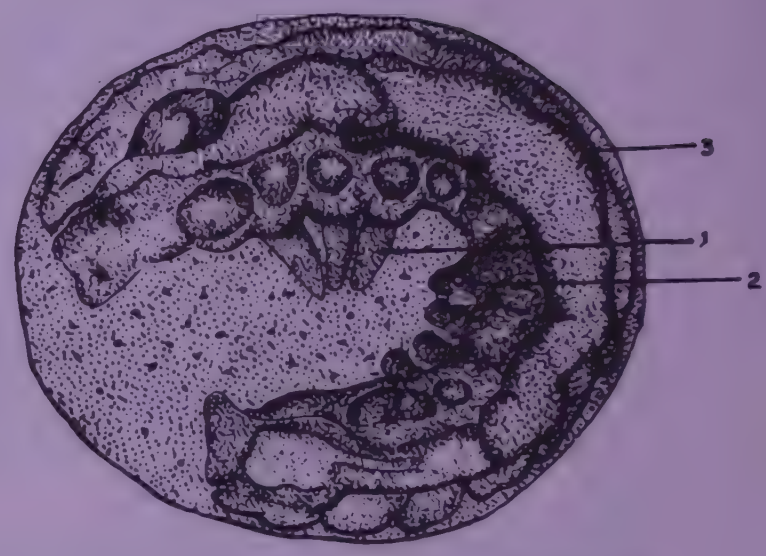
Fig. 25 — Egg 5 days after laying

The anterior segments of the embryo fuse together and form the head. Thoracic appendages develop and become three segmented legs. The last three segments of the abdomen fuse together so that the abdomen has only nine segments. The embryo now starts to move around as it seeks its correct position in the egg; for instance the embryo that was in a supine position with its abdomen facing the outer of the egg turns round so that its abdomen faces the inner side. This is called blastokinesis, or involution or revolution of the embryo.

Completion of embryonic development (Figs. 26–29)

1 Segmentation of the body

Fig. 26 — Egg 6 days after laying



1 Thoracic legs 2 Abdominal legs

3 Midgut

Fig. 27 — Egg 7 days after laying

1. Ocelli
2. Setal hairs

Fig. 28 — Egg 8 days after laying

1. Ocelli
2. Setal hairs

Fig. 29 — Egg 9 days after laying

After blastokinesis, the embryo continues to develop and the rest of the organs from the ectoderm and mesoderm are formed. The skin, antennae, mouth, thoracic legs, abdominal legs, silk glands, Malpighian tubules, nervous system, endoskeleton in the head ocelli, fore and hind-guts, and the external sexual organs, muscles, dorsal vessel, blood cells, suboesophageal gland and fat body are formed from the mesoderm. The mid-gut is formed from the endoderm.

Bristles grow on the body surface and then dark pigmentation occurs in the region of the mouth and head. When the head pigment first appears it can be seen through the egg shell as a blue spot and this stage is called the "eye spot" stage. On the following day the whole body of the embryo turns black due to the development of body pigments and appears bluish-black through the egg shell: this stage is called the "blue egg" stage. Following the blue egg stage, the egg starts hatching within the next 24 hours (by next morning) and the newly hatched larva appears.

(vii) Genetics

The silkworm *Bombyx mori* has attracted great attention from geneticists from all over the world since it is an ideal animal (next only to *Drosophila*) for experimental study in genetic science in view of the great number of heritable characteristics in the egg, larval, pupal and adult stages and the comparatively short life cycle which enables four to six generations to be bred in a year. Much information is therefore available on the genetics of the silkworm but in this section of the manual a brief reference will be made only to those aspects that apply to the silk industry.

Silkworm chromosomes

Through cytological studies it has been established that the haploid number of chromosomes in *Bombyx mori* is 28 in the egg and the spermatozoa, with double that number in the somatic cells. The near relatives of the domesticated silkworm at present in existence are *Bombyx mandarina* Moore and *Theophila religiosae* Helf which have a 27 and 31 haploid number of chromosomes respectively. In a variety of *Bombyx mandarina* found in Manchuria and Central China and another variety in Taiwan the number is 38. Therefore it is now presumed that *Bombyx mori* have evolved from the 28 haploid number variety of *Bombyx mandarina*.

Natural polyploids are rarely found in silkworms. However, artificial polyploids can be easily produced by physical and chemical stimuli such as centrifugal force, high temperature, colchicine and so on. But the polyploids produced in this manner though somewhat larger in size than the diploids were of no practical use because of their high sterility rate. Economically also they were no more useful since the number of silk gland cells decreased with the increase in ploidy. In fact the polyploids produce were found to be less valuable commercially than the diploids.

Heredity

A large number of heritable characteristics in *Bombyx mori* have been studied; and over 260 qualitative and quantitative traits observed in the egg, larval, pupal and adult stages of the silkworm have been studied so far.

Although most organisms exhibit recombination of linked genes both in males and females in varying degrees, such a recombination occurs only in the male silkworm, i.e., it is confined to the homogametic sex. To date, on the basis of studies conducted to determine crossing-over percentages, linkage maps have been prepared for 19 chromosomes; the remaining 9 have not yet been fully studied. Eighty-one loci have been determined so far on the 19 linkage maps.

A study of the hormonal mechanism controlling the hibernating trait has revealed that suboesophageal ganglia secrete the diapausing substance of the egg during the pupal stage. The activity of the suboesophageal ganglia is influenced by the brain. The environmental conditions controlling voltinism act directly on the brain which stimulates the suboesophageal ganglia.

The interaction of genes in the hormonal secretion of the various glands controlling the physiology of hibernation can be summarized as follows:

1. Maturity genes control the function of the *corpus allatum,* which secretes the juvenile hormone.
2. Moulting genes control the activity of the prothoracic gland, which secretes ecdyson.
3. Voltinism genes control the activity of the suboesophageal ganglion, which secretes the hibernating substance.

(viii) Exploitation of heterosis

The phenomenon of heterosis or hybrid vigour has been fully exploited in both animal as well as plant production. The classical examples of the application of this phenomenon are corn in agriculture and silkworms in sericulture. Heterosis is the genetic expression of the beneficial effects of hybridization. In silkworms a marked improvement in several characteristics of economic importance has been observed in F_1 hybrids between breeds belonging to different regional races. This was first observed in Japan when crosses between different Japanese, Chinese and European races were carried out. As a result of these studies the rearing of hybrid eggs was introduced into Japan in about 1914. The yields obtained from these hybrids were so phenomenal compared to those from pure species that the rearing of hybrids spread very quickly and within five years the entire country took to the rearing of hybrids. Since then throughout practically the whole world only hybrids are exploited for commercial cocoon production.

The advantages of rearing hybrid silkworms are:

(i) larval period is shorter;

(ii) leaf–cocoon ratio is low;

(iii) mortality is reduced;

(iv) cocoon weight and the shell weight are high;

(v) filament length of fibre is longer;

(vi) silk filament is thicker;

(vii) cocoons are more uniform in size and shape.

The hybrids may be straight single crosses between two parental races. At present Japanese and Chinese races are usually crossed to produce the straight hybrid eggs. Occasionally in highly productive races where normally the egg production is comparatively low, a three–way cross or even a double–cross may be employed for ease of egg production. To produce double–cross eggs, usually two allied strains say Chinese + Chinese and Japanese + Japanese are crossed first and then the F_1 hybrids produced are crossed to produce the double–cross eggs.

In this way the seed production becomes easy and cheap since the second stage seed cocoon crop is easily raised as rearing involves rearing of F_1s.

Through systematic and scientific methods of race breeding newer and more productive silkworms races are continuously being evolved to meet technological requirements of the sericulture industry. Based on scientific studies of the new races suitable improved hybrid combinations are established for the production of hybrid seeds for commercial exploitation.

Chapter 3

SILKWORM EGGS

(i) Production

Silkworm eggs can be divided into hibernating and non–hibernating eggs.

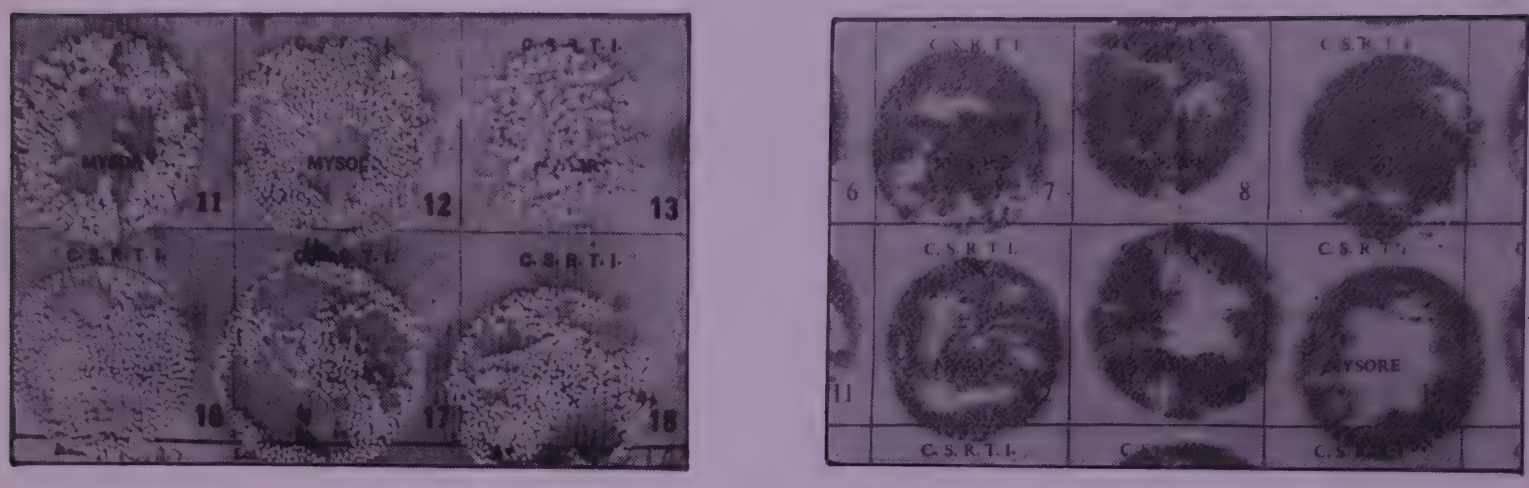


Fig. 31 — Hibernating and non-hibernating silkworm eggs

In hibernating eggs the embryo develops only half–way, undergoes a stage of dormancy called diapause, and hatches out the following spring. In non–hibernating eggs, on the other hand, the embryo develops without undergoing disapause and hatches out in the normal way. Under fixed environmental conditions, this characteristic depends upon the hereditary factor of the silkworms namely whether the egg produced is hibernating or not.

Silkworms laying hibernating eggs in Spring, which do not hatch out till the following spring, so producing only one generation in a year, are called univoltines. When the first generation of moths lays non–hibernating eggs and the second generation lays hibernating eggs which hatch out only in the following spring so that there are two generations in a year, then such silkworms are known as bivoltines. Silkworms which lay non–hibernating eggs and so are able to produce many generations in a year are called multivoltines.

Generally univoltine silkworms lay only hibernating eggs and multivoltine races lay only non–hibernating eggs while the behaviour of the eggs of the bivoltines is intermediate. Eggs of multivoltines do not normally hibernate, and hatch in eight to ten days, while the univoltine and bivoltine races lay hibernating eggs which require special treatment to make them hatch. This trait can change under different environmental conditions but silkworms are broadly classified as univoltine, bivoltine and multivoltine.

Silkworm seed production

The most important step in silkworm rearing is the production of the silkworm eggs required for rearing. The silkworm eggs, or seeds, required for commercial rearing should be of high quality and free from disease. On innumerable occasions the entire sericulture industry has been ruined through lack of appreciation of the need for healthy high–quality silkworm seeds. The production and supply of disease-free silkworm eggs is highly specialized work involving technical and scientific skills. To produce

good quality seeds there must be a sound seed organisation. Realising the importance of quality seeds in the development of the sericulture industry, sericulture countries all over the world have established a network of institutions both for research on egg productionand for commercial production of quality eggs.

Silkworm seeds can be broadly classified as reproductive seeds or industrial seeds.

Reproductive seeds

Reproductive seeds, or eggs, are those intended for producing the seed cocoons which are required in large numbers for producing commercial hybrid eggs or industrial seeds. These pure lines are difficult to rear and so special care must be taken and ideal rearing conditions provided. These are sold at premium price of 30–50 percent more than reeling cocoons.

Industrial seeds

Industrial seeds are generally specific hybrids between two or more pure lines or races of silkworms and are reared by the sericulturists for producing cocoons on a commercial scale for reeling purposes. After multiplying the reproductive seeds to meet the needs of the industrial seeds the latter are prepared by crosses between parental races for producing the hybrid seed.

Since silkworm moths lay on average 400–500 eggs it is theoretically possible to have the seeds multiplied 200–250 times from generation to generation, assuming that the sexes are equal in number. But allowing for mortality and rigid selection of good quality seed cocoons and healthy layings up to one hundredfold increase from generation to generation can be easily achieved. Since repeated large-scale multiplication can lead to fast deterioration in the quality of the cocoons, scientific seed production aims at two to three stage multiplication only from the stage of nucleus stock to the stage of the industrial seed. During every stage of multiplication rigid selections are enforced so that even at the last stage of mass multiplication the quality of the cocoons is maintained. Seed organisations based on the above concept are envisaged for the production of the commercial silkworm eggs required in large quantities for silkworm rearing purposes.

At the Research Institutions and the Race Breeding Experimental Centres, races which have been accepted by National Committees or Special Committees as suitable as parental species are maintained in a high state of productivity and breeding true to racial characteristics. These centres supply the basic or initial material for multiplication to the Breeding Centres. At the Breeding Centres the basic seed required to produce the reproductive seed is prepared. At the Reproductive Centres the parental seeds are produced which are supplied to seed cocoon rearers who produce the seed cocoons. These seed cocoons are brought to the Industrial Seed-producing grainages to produce the hybrid seeds. These three-stage multiplication centres are referred to for convenience, as P_3, P_2 and P_1 stations respectively. They are normally organised on a three-tier basis covering three years or sometimes cut to a two-year process when basic seeds are directly supplied by the P_3 stations.

Up till the preparation of the reproductive seed the rearings are conducted on an individual laying basis, referred to as cellular rearing so as to keep constant watch over the purity and health of the seed crops. At the P_1 stage, mass-scale rearings are carried out in convenient batch rearings.

Grainages

Grainages are establishments where disease-free and quality seeds are produced on scientific lines. A grainage may handle either reproductive seed or industrial seed. It may be either Government owned or privately owned. Generally grainages where the layings of the parental races are produced are managed by Governmental agencies, whereas the industrial seed grainages may be private or government owned. It is the responsibility of the grainages to produce sufficient quantities of both reproductive seeds and industrial seeds to meet the demands of the sericulture industry. The functions and activities of the grainages are the following:

Selection of seed cocoons

In order to produce good quality and healthy eggs the seed cocoons used for the purpose must be of high quality and in good health, and therefore the seed cocoons arriving at the grainages are subjected to rigid selection. In selecting lots of seed cocoons, past histoy such as the source of seed, progress of crop, yield of cocoons and other qualitative characters are taken into account. For selected lots only sound and uniform cocoons conforming to the characteristics of the race of the parental stock are selected, and defective and deformed cocoons, under and over-sized cocoons, double, stained and dead cocoons, etc., are rejected.

Sometimes even a preliminary pupae test for freedom from diseases is also required. Deformed, flimsy and dead cocoons are taken and subjected to microscopic examination after crushing the pupae. If such an examination should reveal more than 10 per cent of pebrine infection or any other disease, the entire lot is rjected and not used for seed purposes. After the good quality seed cocoons have been selected, they are preserved under ideal conditions for the emergence of the moths.

Protection of seed cocoons and emergence of moths

The selected seed cocoons should be preserved in a well-ventilated room and spread out in thin layers on cocoons trays arranged on stands **Fig. 32**

Fig. 32 — Wooden stands with trays for preservation of seed cocoons

The temperature and humidity in the room should also be maintained as far as possible at optimum levels for uniform development of the pupae into moths and the consequent uniform emergence of healthy moths from the seed cocoons. Too low a temperature slows down development and if the temperature is very high it will unduly hasten development resulting in the emergence of weak moths. Too wide fluctuations in temperature will also lead to uneven development and irregular emergence of moths. Therefore, the seed cocoons should be preserved within the optimum range of 23–25°C. At too extreme temperatures below 20°C and above 30°C the number of eggs laid is reduced and the number of unfertilized eggs also increases.

Similarly too low humidity or too high humidity should be avoided. The optimum humidity for preservation of seed cocoons is between 75 and 80 percent.

The preservation room should be well ventilated with proper circulation of air to drive away gases such as carbondioxide being given out by the live pupae. Strong wind and direct sunlight also should be avoided. As already stated, the cocoons should be arranged in thin layers preferably of a single layer of cocoons in trays and they should not be piled up in heaps. Over the thin layer, perforated paper is placed through which the emerging moths make their way out; this facilitates the easy picking of moths for mating. Under the above conditions of proper storage of cocoons moth emergence can be expected to be uniform. In grainages in technologically advanced countries, to facilitate the easy emergence of the moth from the cocoon shell, both ends of the cocoons are cut so that the moth is able to emerge freely without having to spend considerable energy cutting through the tough cocoon shell.

Care must be taken to ensure that the moths emerge simultaneously. Therefore, in preparing hybrid layings steps have to be taken to ensure the simultaneous emergences of parental moths. This is achieved by so brushing and commencing the rearing of the parental species which have different larval duration, that all the moths emerge at about the same time. If, in spite of the care taken, there should be still differences in the emergence of moths of the parental races, cocoons which are expected to emerge early can be safely preserved for two or three days at a temperature of 50°C when they are three to five days old after pupation. Even male moths can be safely stored for about a week at a temperature of 70°C for mating purposes after the emergence.

Emergence of moths occurs early in the morning (Fig. 33), often, to ensure more uniform and simultaneous emergence of moths, the rooms housing the seed cocoons are kept dark and suddenly lights are put on so that moths emerge all at once. This may be done two hours prior to picking of the moths for mating purposes.

Fig. 33 — Emergence of moths

Sex separation

In the case of preparation of industrial seeds which are invariably hybrid seeds, the sexes must be separated beforehand so that selfing in the same parental race does not occur. This sexing may be carried out either in the pupal or the larval stage by making use of the differences in the sexual markings of the late-fifth instar larvae and the pupae. In Japan in the case of seed cocoon rearing, sexing is done mostly in the late fifth-instar prior to mounting and the sexes are separately mounted. In the U.S.S.R. the differential weights of the cocoons of males (lighter) and females (heavier) are taken advantage of to separate the sexes with sex-separating machines. Recently races with sex-limited larval markings have been produced to facilitate sex separation in the larval stage itself.

In some of the less advanced sericulture countries sex separation is not carried out till the moths emerge, and the males and females are picked immediately after emergence. Generally the males emerge first and can be picked before the females emerge and kept separately. Later when the females also emerge, one should be ready to pick out males and females separately so as to prevent their mating within the same parental stock. Since the females are bigger than the males and are also less active and have swollen abdomens and prominent ovipositors they can be easily distinguished and separated from the males. The males are generally more active, smaller and with narrower abdomens (Fig. 34a).

Fig. 34 (a) — Left: Male moths Right: Female moths

Only normal, healthy and active moths of both sexes are used for preparing the eggs; undersized, deformed and less active moths are rejected.

Copulation and oviposition (Fig. 34b)

Moths have a tendency to pair immediately after emergence and, therefore, the female moths required to copulate with the male moths are allowed their mates for copulation. The required number of females are kept in trays with proper spacing and supplied with an equal number of males by broadcasting the latter into the tray. The pairs come together immediately and copulate. Approximately three hours of mating is sufficient since during this period at least two ejaculations occur, the first during the first 30 minutes and the second after one to one and a half hours. During copulation, the coupling pairs are kept in semi-dark conditions and preferably at a temperature of 24°–25°C. After the copulation the moths are separated by holding the female lightly and moving the male sideways with the fingers of right hand. This facilitates easy separation without injury to the female reproductory organs. The females are then kept for egg laying.

The females intended for egg laying are first placed on a piece of paper which is tapped to induce them to pass urine. Later they are placed on egg cards if the layings are meant to be prepared on cards and sold by number, or on paste-coated craft paper if the intention is to prepare loose eggs in boxes. In preparing eggs on egg cards, the oviposting female is kept individually in a cellule or a moth funnel over the egg card; in the case of loose-egg preparation 50–100 moths are put on the paste-coated craft paper and placed on a tray. In the case of latter the trays are closed on all sides.

Fig. 34 (b) — Copulation and oviposition

In preparing the reproductive seed, normally the male is mated once only with the female. On the other hand, while preparing industrial seed, if there is a scarcity of males, the males can be used for a second mating after resting for some time between the two matings. However, the duration of the second mating should be longer than the first to ensure effective second copulation.

The moths usually lay eggs from the afternoon onward and reach the peak of oviposition by 18.00-20.00 hours. By the next morning the majority of the eggs will have been laid: from 400-500 eggs in the case of univoltine and bivoltine races and 300-400 in the case of multivoltine race on average.

Moth examination

After the female moths have laid their eggs they are subjected to microscopic examination to see if the moth is free from disease or not. In most countries the law provides that eggs must be free from diseases. Since pebrine spores are easily transmitted from the diseased mother moth to the eggs, examination of the female mother moths must be carried out to ensure that their layings are free from disease.

In the case of reproductive seeds all the moths are examined on an 100 per cent basis individually and only disease-free layings are carried forward for producing the seed cocoons for preparing industrial layings. In the preparation of industrial seeds, however, in view of the very large number of moths involved, it is not possible to carry out a 100 per cent single moth examination and, therefore, only sample test is carried out where the percentage is high if the number of moths in the lot is low and vice versa.

In conducting the examination (Fig. 35) the moths are put into a mortar to which a small quantity of 2 percent caustic potash or soda solution is added and ground with a pestle. The crushed juice is spread on a glass slide, covered with a cover slip and examined under a microscope with a magnification of 600 for pebrine spores. (Figs. 36, 37).

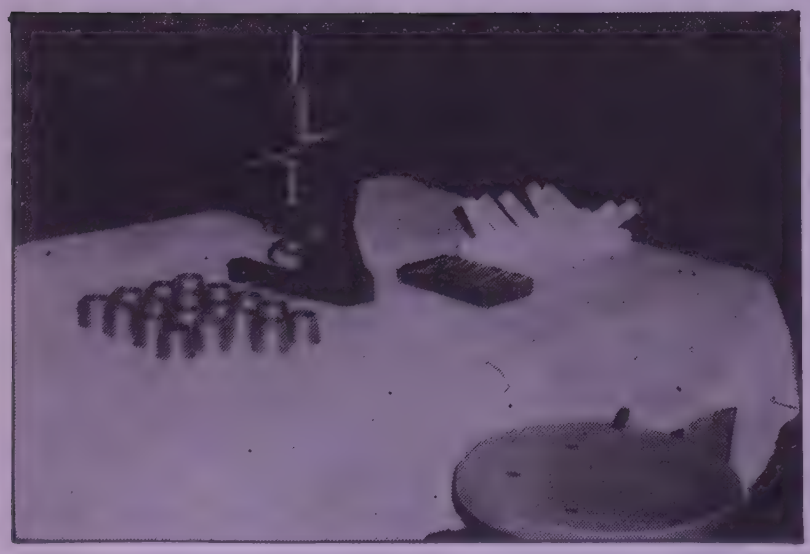


Fig. 35 — Equipment for microscopic examination

Fig. 36 — Moth crushing machine

Fig. 37 — Microscopic examination for diseases

If the pebrine spores are present the eggs laid by the individual moth, or batch of moths, if the examination is on a sample basis, are rejected.

In the case of uni and bivoltine races which normally hibernate, the moths can be conveniently dried and examined at leisure. But in the case of multivoltine races the entire process of moth examination and selection of disease-free layings should be conducted within the short time available of about a week before hatching.

Washing of the silkworm eggs

In the case of multivoltine eggs normally reared in India, the eggs are invariably prepared on egg cards. The eggs are soaked first in 2 percent formaldehyde solution for about an hour to disinfect the egg surface and also to fix the eggs safely onto the egg cards. Afterwards, the egg cards are washed in running cold water to wash the eggs free of traces of formaldehyde. They are later hung in the shade in the open for drying. Immediately after drying they are taken for incubation.

In the case of eggs laid on paste-coated craft paper for preparing loose eggs, the eggs are detached from the egg sheets by soaking them in water about an hour and the loosened eggs are again washed with a salt solution of 1.06–1.10 specific gravity to separate out the unfertilized, dead eggs, etc., which float on the surface. Washings in the case of hibernating eggs are generally carried out in December when the room temperature is sufficiently low, but not too low to activate the eggs. Prior to the final washing the eggs are disinfected with a 2 percent formalin solution.

The eggs are later dried by spreading them thinly on any absorbent base and if necessary by running electric fans. Before the eggs have completely dried, they may be carefully worked out by hand or with a soft apatula to break up the agglutinating eggs. The loose dried eggs are then winnowed out to eliminate any crushed or dead eggs. They are then weighed to the required standard and packed in small flat cases or boxes with muslin covers both at the base and the top.

(ii) Protection

In silkworm rearing it is important not only to produce silkworm eggs of the high quality described above, but also to carefully protect and preserve them to ensure good and uniform hatching, the production of healthy larvae and good quality cocoons. In temperate regions such as Japan, the univoltine and bivoltine races lay hibernating eggs and such eggs have a higher output of silk compared to the non-hibernating eggs of the multivoltine varieties of the tropical areas. Since the highly productive bivoltine and univoltine races thrive well in temperate regions, care is taken to produce only hibernating eggs for increased output of silk in these regions. Hibernating eggs are properly treated and preserved for uniform and good hatching the following spring.

In the hibernating eggs a hormone responsible for the inhibition of development of the embryo is present, the effect of which can be neutralized only by a definite spell of cold temperature treatment which destroys the hormones. Once the effect of this hormone is nullified, the eggs become activated and are referred to as activated eggs. The duration of aestivation period, ie., the duration of the higher temperature at which the egg is kept, and the related duration of cold temperature treatment required to break the diapause have been worked out, and, on the basis of these findings, eggs laid in any season can be properly preserved and hatched as required during the following spring.

The most important point to be considered in the preservation of hibernating eggs is the prolongation of the storage period by utilizing the diapause that can be made to last for an adequate length of time through proper temperature control until the beginning of incubation so as to ensure uniform hatching of eggs.

Preservation of eggs from one spring crop until the following spring

Hybrid eggs prepared by the middle of June from the preceding spring season cocoons are stored for 60 days until the middle of August at an aestivation temperature of 23°–25°C. This helps the egg to enter into stable diapause immediately. The eggs may then be left at the natural temperature which gradally falls to approximately 20°C by the end of September or early October. Should natural temperature be higher, it must be lowered artifically to 20°C. With the onset of winter the normal temperature falls further and so by about December when it is down to 5°C, the eggs are washed off from the cards and kept at 5°C for 50–60 days. This temperature treatment is ideal for awakening the embryo from diapause. It also helps to inhibit further development of the awakened embryo thus ensuring uniform developemnt of all the eggs. Since at 5°C the storage capacity of the eggs is limited , at the end of January or early February they are transferred to a still colder temperature of 2.5°C for 40–60 days. At this temperature, the development of the embryo is completely arrested and long preservation of the eggs is possible. About the middle or end of March the eggs are again given a special treatment called intermediate care when they are kept at a temperature between 10 and 15°C for about four to five days to prolong the storage life. Then they are stored once again at 2.5°C till the eggs have to be taken out for incubation.

Preservation of autum eggs till the following spring

Hibernating hybrid eggs laid in late August or in early autumn are kept at 23⁰–25⁰C for about 30 days till late September; then at 20⁰C till the middle of October. The eggs may be kept at natural temperatures which become lower till December and from then on the eggs may be handled in the same way as eggs produced in the spring.

Hybrid eggs laid in late autumn, i.e., by the middle of October, are aestivated at 23⁰–25⁰C for about 20 days till early November. The temperature is then gradually lowered at the rate of 2.5⁰C every three days until the natural temperature is reached. After this the eggs are again handled almost in the same way as the eggs laid in the spring. Since the duration of preservation is short it is not necessary to resort to any intermediate care for eggs by raising the temperature to between 10⁰ to 15⁰C in March as was done for the eggs prepared from the spring crop.

(iii) **Artificial hatching**

Although hybrid eggs left to the nature will not hatch till the following spring, artificial methods are now available to make them hatch at any time. Artificial methods are widely employed for summer and autumn crop rearings where the spring–produced eggs are invariably used to utilise the new leaves which become available in those seasons. Among the various methods of physical stimuli tried to induce the artificial hatching, the most successful and the only method practised at present is the simple and reliable acid treatment for artificial hatching. In Japan alone 60 percent of the cocoon production comes from summer and autumn crops and, therefore,about the same percentage of the eggs produced in the country is subjected to acid treatment for artificial hatching. This illustrates clearly the important role of artificial hatching by the sericulture industry.

In tropical areas such as India, where mulberry production is plentiful and continuous throughout the year, the silk output can be increased by introducing hardy bivoltine silkworm races which can be reared five to six times during the year through artificial hatching of hibernating eggs.

Common acid treatment

Fig. 38 — Hydrochloric acid treatment equipment

The common method of acid treatment is to subject the freshly laid hybrid eggs within 20–24 hours of laying to hydrochloric acid which stops the eggs from entering into diapause. The acid treatment is most effective when the eggs treated within 20–24 hours of laying have been kept at the temperature of 25°C. This emphasizes the need for the counting of the larvae, the preservation of the seed cocoons and the preparation of the eggs to be carried out at the optimum temperature of 24°–25°C in order to obtain the best hatching results after the acid treatment.

Prior to acid treatment the eggs must be fixed to the egg cards by first dipping the eggs and the card in a 2 per cent formaldehyde solution and then drying them thus fixing the eggs firmly to the card.

In the case of the preparation of loose eggs meant for industrial seed the eggs are first washed–off from the card, dried, and put in a special container for acid treatment. To obtain the best results, the hydrochloric acid used must be absolutely pure and should have a specific gravity of 1.064 at 46.1°C when the acid treatment is conducted. Through repeated use, the strength of the hydrochloric acid is likely to decrease and must be corrected periodically. Treatment usually lasts about four to six minutes but this depends on the different races, or the age of the egg when subjected to treatment. Normally univoltine eggs take a little longer than bivoltine eggs. During the treatment the temperature should be kept constant at 46.1°C. Immediately after the treatment the eggs are washed thoroughly in cold running water at a temperature of about 20°C to wash off any traces of the hydrochloric acid and the eggs are later dried.

The acid treatment can also be conducted with hydrochloric acid at ordinary room temperature; this is called "cold acid treatment". With this method the eggs are treated in a hydrochloric acid solution of a concentration of 1.1 specific gravity for approximately an hour at 25°C. But this method is not as popular as the hot acid treatment.

Eggs treated with hydrochloric acid for artificial hatching and afterwards incubated will normally develop and hatch in about 10 days. If, however, the treated eggs are to be delayed for some time they can be kept for 20 days or so in cold storage at 2.5°C. Should it be necessary to postpone the acid treatment itself, then it is possible to cold store the 20–24 hour old–eggs at 5°C for about a week prior to acid treatment. In such cases it is important that the humidity during the cold storing be kept at the optimum level of 75–80 percent for safe storage.

Acid treatment after chilling

As mentioned above, with the common acid treatment method eggs can be made to hatch within 10–30 days by immediate acid treatment followed by cold storage for about 20 days. If hatching is delayed for more than 30 days, acid treatment can be carried out only after due chilling. This is known as acid treatment after chilling. With this method approximately two day old eggs are chilled for a certain period so as to awaken the embryo from diapause and when the embryo is awakened the acid treatment takes place. Chilling is ordinarily carried out for a minimum period of 40 days before the acid treatment and this gives extremely satisfactory results. If chilling lasts only 25–30 days the hatching may not be entirely satisfactory.

In the normal acid treatment after chilling for 40 days and more, freshly laid eggs kept at 25°C for 40–50 hours are chilled at 5°C for 40–60 days. If chilling is to be prolonged beyond 60 days, it is first carried out at 5°C for about 40 days and then at the lower temperature of 2.5°C. Care should be taken to keep the humidity at the optimum level of 75–80 percent during chilling to avoid dessication of eggs.

After being removed from cold storage the eggs are left for at least two hours at 25°C and later on subjected to acid treatement. In this case the specific gravity of the hydrochloric acid should be 1.085 at 47.8°C when the acid treatment is conducted. This treatment last slightly longer than ordinary acid treatment. It may be from five to seven minutes. Normally a shorter treatment period is required in case of eggs chilled for a longer period.

If the chilling period is to be shortened the eggs kept first at 25°C for 40–45 hours are chilled at 5°C for periods ranging from 25–35 days. In this case the concentration and temperature of the hydrochloric acid as also the duration period are the same as for acid treatment after ordinary chilling.

(iv) **Incubation**

Incubation of silkworm eggs aims at uniform development of the embryo thereby securing uniform hatching through proper maintenance of environmental conditions. In addition, the conditions of incubation greatly influence the voltinism character of the egg in the succeeding generation and also the larval growth and the success of the cocoon crop itself including cocoon quality. Therefore, the eggs after the necessary cold preservation treatment and acid treatment for artificial hatching should be subjected to ideal incubation conditions.

The egg incubation room or chamber should be absolutely clean and steps to disinfect the incubation room and appliances used in the room must be taken in time. Heating or cooling arrangements must be perfect so as to maintain uniform temperature throughout the incubation room. The egg cards and egg cases should be so arranged inside the rearing room that all the eggs are exposed to the temperature and humidity maintained in the room.

Optimum humidity in the incubation room is 80–85 per cent. Optimum temperature for the incubation of non–hibernating eggs and eggs after acid treatment for immediate hatching is 24°–25°C right from the beginning.

Over–wintered eggs taken out of cold storage are not immediately taken for incubation at 24°C–25°C but are brought to this temperature gradually. They are at first kept at a temperature of 15°C for three days and later subjected to the normal incubation temperature of 24°–25°C. This intermediate step avoids the sudden violent change from 2.5°C — 24°–25°C and also helps in uniform development of the embryo. Eggs that have been cold stored after acid treatment for delaying hatching should be kept at 15°C for 12 hours before they are brought to the normal incubation temperature of 24°–25°C.

Towards the end of the incubation period at the blue spot or eye spot stage, the eggs are kept in dark boxes or placed so that their hatching can be more uniform on the next day.

If for any unexpected reason hatching has to be delayed after incubation has started, this can be done to a limited extent by cold storing the eggs at 5°C on the second or third day of incubation for about a week. Hatching can also be delayed at the blue egg stage by cold storing for about a week at 5°C. If brushing has to be delayed after hatching, the newly hatched larvae can be cold stored for about three days at 7.5°–10°C.

It is important to ensure that the humidity during the cold treatment never falls below 75 percent.

Chapter 4

SILKWORM REARING

(i) Rearing programme

In sericulture areas which enjoy temperate or subtropical climates, silkworms rearing is carried out twice a year in the spring and the autumn or three times, in the spring, the summer and the autumn, coinciding with the growth and production of mulberry leaves. In tropical areas, however, where mulberry growth is continuous throughout the year silkworms are reared five to six times in a year. Whether rearings are conducted frequently or only two or three times a year it is always beneficial to have a planned programme. It is advisable to rear a greater number of layings at a time than to rear many batches at very short intervals. The programme of silkworm rearing in a farm is determined by the following considerations:

1. Conditions of mulberry growth and yield of mulberry leaf.
2. Availability of labour for rearing silkworms.
3. Facilities for rearing silkworms. i.e. suitable buildings and equipment.

1. Conditions of mulberry tree growth and yield of mulberry leaf

The time to rear silworms is when there is a proper sprouting of mulberry leaves and a plentiful supply of good quality leaves. The yield and the quality of the leaf depend to a great extent on the agronomic practices followed for the cultivation of mulberry trees namely irrigation, application of fertilizers and proper activation.

The volume of silkworm rearing to be undertaken is determined by the availability of leaf. This is calculated by estimating the yield of mulberry trees in the previous crops and during the corresponding season of the previous years. The estimation of mulberry leaf in the garden has to be accurate as shortage of leaf during rearing may lead not only to poor crops but also to considerable hardship in rearing.

It can be safely estimated that 20000 to 25000 kg of leaves can be harvested per hectare per year under conditions of optimum agronomic practices. In areas where there are limitations as regards moisture and fertilizers, mulberry productivity will be coniserably affected and the yields considerably lower. On the basis of the seasonal availability of leaves, the number of layings or the quantity of eggs to be reared is decided upon. It has been estimated that to rear one box or 20000 eggs 600–650 kg of leaves are required for spring and 500–550 kg for autumn rearings in Japan. In tropical areas such as India to rear 20000 eggs, or say 50 layings, the quantity of leaf required is about 350–400 kg.

2. Availability of labour

Since sericulture is a labour–intensive rural industry requiring much labour the volume of rearing to be undertaken will also depend on the adequate availability of labour at a reasonable wage. If labour costs are high economic production costs will also increase.

In Japan four people are required to produce ten kg of cocoons. In tropical areas such as India the labour required to produce this quantity is almost the same if improved scientific technqiues are followed. The traditional method of rearing followed in India is more labour consuming and since sericulture is a subsidiary industry to agriculture, the labour requirement is adjusted to the main agricultural labour operations and also enlists the otherwise idle labour of the women who do not generally work on agricultural operations.

3. Facilities for rearing silkworms

The facilities required for silkworm rearing are a rearing space or houses, and rearing equipment.

(a) Rearing space or houses

Silkworm rearing demands certain specified environmental conditions particularly as regards temperature and humidity. Rearing houses are planned and constructed to provide and maintain proper environmental conditions to ensure good quality cocoons. One of the main criteria for deciding the size and number of rearing houses required is the size of the mulberry garden and the leaf yield.

Generally three types of rearings are known: shelf rearing, shoot rearing and floor rearing. In shelf rearing, rearing trays of convenient sizes are arranged on stands with eight to ten tiers. Shelf rearing economizes on space and in a given area a maximum number of eggs can be reared. In the case of shoot rearing, which is a recent innovation, the rearings are usually carried out in two or three tiers of convenient length and breadth of rearing beds. In the case of floor rearing the worms are reared right on the floor on a raised platform in beds of convenient length and breadth.

A model rearing house for shelf rearing

A model rearing house of convenient size for shelf rearing is shown in Fig. 39. It is a rat-proof building with a ledge all around to prevent rats from entering the building. The building has a verandah all around and glass windows and doors to provide good ventilation and light. The ceiling of the rearing house is generally made of wood; if made of concrete or tiles a false ceiling must be constructed. Ventilators must be installed to ensure free circulation of air.

The rearing house is partitioned into four convenient rooms in one of which, by maintaining high temperature and humidity, the young age silkworms are reared. The rooms are provided with an adequate number of windows and doors to ensure good ventilation for rearing older silkworms.

The rearing houses should be located in such a manner as to maintain as far as possible ideal temperature and humidity conditions inside the rearing rooms. In temperate and sub-tropical regions they should be constructed in a north-south direction so that maximum sunlight and heat is available to warm up the rearing rooms adequately. In tropical regions, however, the building should be sited east-west so that too hot, direct sunlight is avoided and cooler room temperatures maintained.

Recently there has been a tendency to use improvised rearing sheds with roof and side walls made of plastic sheets or tarpaulins which prevent direct draughts of cold air from outside entering the sheds. This type of shed is usually used for shoot or floor rearings.

In certain countries such as India, where mostly shelf rearing is practised, there are no separate rearing houses as such, but the rearing is done in the dwelling houses themselves. Similarly in Jammu and Kashmir in India, where mostly floor rearing is practised, this too is done in the rearers own houses.

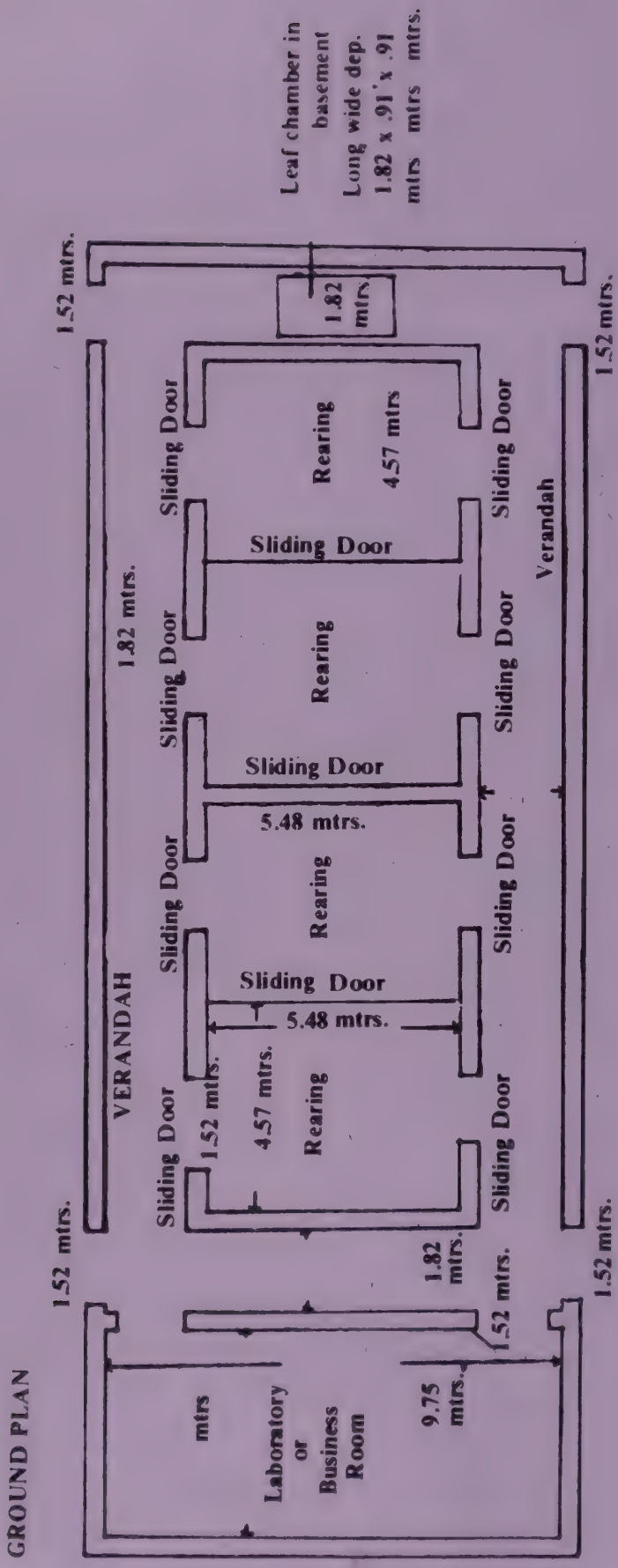


Fig. 39a, b — Plans of building for rearing operations

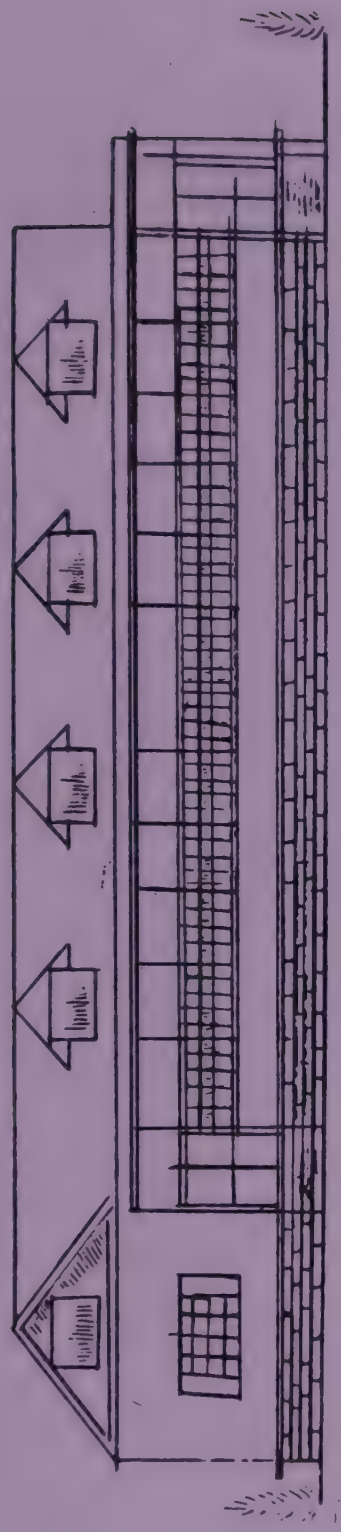


Fig. 39b, c — Plans of building for rearing operations

(b) Equipment for silkworm rearing

The equipment required for a model rearing house for shelf rearing is as follows: In the model rearing house in each of the rooms 200–250 layings, or 800–1000 layings in the entire rearing house can be reared under self rearing.

Rearing stands

Fig. 40 — Rearing stand with rectangular wooden trays

Rearings stands are made of wood or bamboo and are portable so that it is easy to move them from place to place. A rearing stand should be 2.5 m high 1.5 m long and 1 wide and should have 10 shelves with a space of 20 cm between each shelf. The trays are arranged on the shelves and each stand can accommodate ten rearing trays. Six stands are required for each rearing room.

Ant wells

Ant wells are provided to stop ants crawling onto the trays and attacking the silkworms. They are made of concrete or stone blocks 20 cm square and 7.5 cm high with a deep groove of 2.5 cm running all round the top. The legs of the rearing stands rest on the centre of the block and water is poured into the groove to stop the ants reaching the rearing trays; each stand leg must rest in a well.

Rearing trays

These are used to rear silkworms and are usually made of bamboo so that they are light and easy to handle. They are either round with a diameter of 1.2–1.4 m and a depth of 7.5 c or rectangular measuring 0.7–0.9 m x 0.9–1.2 m. On the basis of area of rearing seat required, an adequate number of trays should be provided.

Rectangular wooden trays or boxes (Fig. 40)

These are used for rearing early-stage larvae. They are made of light wood and of convenient size for easy handling. A tray 0.9 m long, 0.7 m wide and 7.5–15 cm deep with the bottom covered may be found convenient. About 80 boxes are required for rearing 800 to 1000 layings up to the second instar.

Paraffin paper

This is thick craft paper coated with paraffin wax with a melting point of 55°C. It is used for rearing early-stage silkworms and prevents withering of the chopped leaves and also helps to maintain proper humidity in the rearing bed.

Foam rubber strips

Long foam rubber strips 2.5 cm wide and 2.5 cm thick dipped in water are kept all around the silkworm rearing bed during the first two instars to maintain optimum humidity. As a substitute, newspaper folded into convenient strips and dipped in water may be used.

Chop sticks

These are made of bamboo approximately 17.5 cm–20 cm long and thin and tapering to one end. Direct handling of the young age worms is to be avoided for hygienic reasons and to prevent damage to young worms. A pair of chop sticks is used to pick early-stage larvae (Fig. 41).

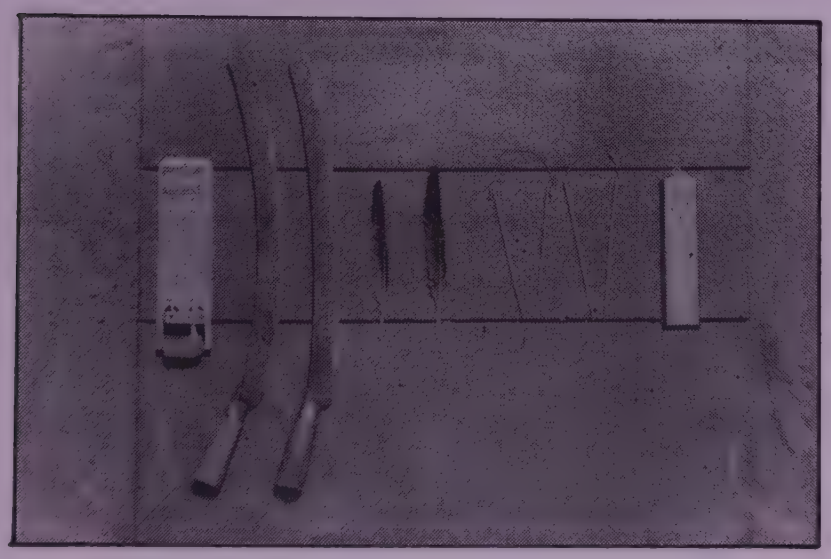


Fig. 41 — Leaf chopping knives, feathers, chopsticks, required for rearing

Feathers

Birds feathers, preferably white ones, are used for brushing the delicate newly hatched worms onto the rearing bed (Fig. 41).

Chopping board

This is made of soft wood and is used for cutting the leaf to the suitable sizes required for feeding the worms in the different instars. The size of the chopping board may be 0.9 m x 0.9 m and 5 cm thick or of any other convenient size.

Chopping knives (Fig. 41)

Chopping knives are used for cutting the mulberry leaves. They are usually 0.3–0.5m long with a broad knife blade and a wooden handle. In technologically advanced countries such as Japan machines, either manual–operated or power–operated, are used for chopping leaves.

Mats

Mats usually 1.2x1.8 m are used for collecting the leaves when chopping is done on the floor; they prevent the dust and dirt on the floor getting mixed in with the leaves.

Leaf Chambers

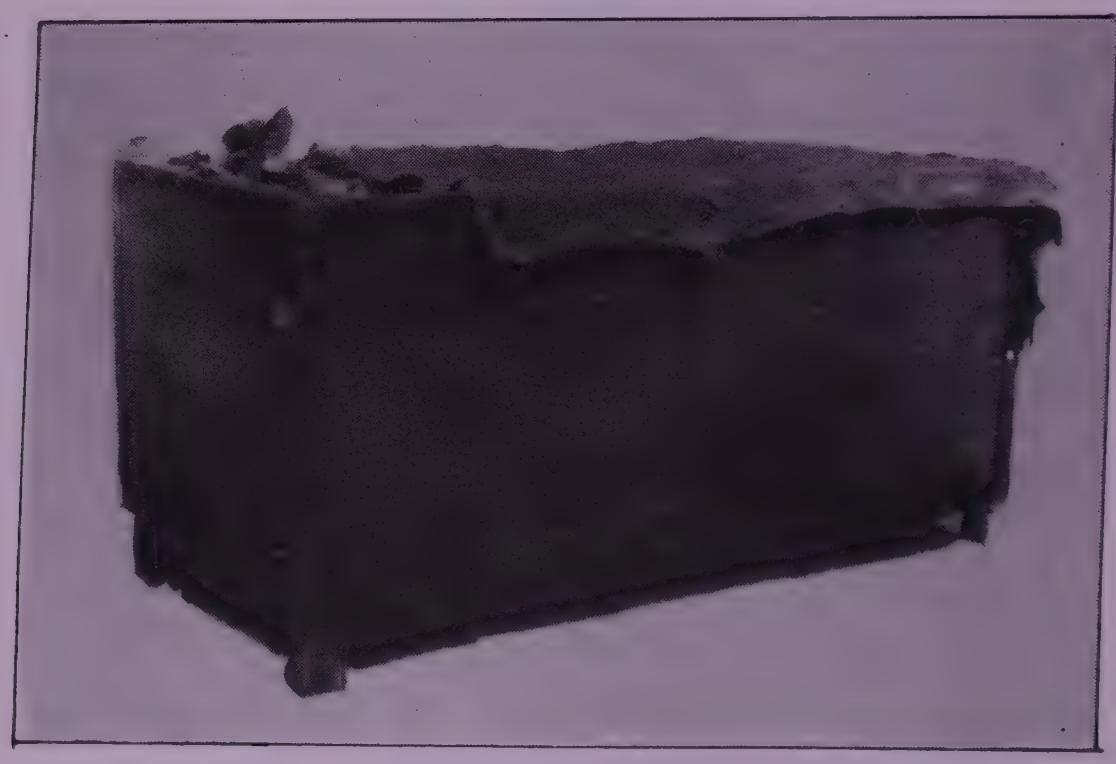


Fig. 42 — Leaf chamber for preservation of mulberry leaves

Mulberry leaves harvested from the field are stored and preserved fresh for feeding the worms at set intervals during the day. The leaves are stored in cool rooms, or in underground masonry pits, or in rooms in heaps covered with cloth or polythene sheets. They can also be stored in convenient leaf chambers, 1.5m long, 0.9 m wide and 0.8 m deep. The side walls and bottom are made of wooden strips 7.5 cm wide and placed 7.5 cm apart. The chamber is covered on all the sides with gunny cloth which is kept wet. During the summer months and dry days the gunny cloth should be sprayed with water repeatedly to prevent the leaves withering.

Cleaning nets

These are made of cotton thread or nylon, woven into nets of different meshes to suit the size variations of different stages of the silkworm. They are used for cleaning the rearing beds and at least two nets are required for each of the rearing trays.

Mountages

These are used as supports for the silkworms to spin cocoons. In India they are made of bamboo usually 1.8m long and 1.2 m wide. Over a mat base, tapes 5–6 cm wide woven out of bamboo are fixed in the form of spirals leaving a gap of 5–6 cm. They are also called chandrikes (Fig. 43). In Japan mountages called revolving mountages or turning cocooning frames are used. (Fig. 44).

Other types of mountages such as centipeds rope mountages, straw cocooning frames etc., are also used. In certain other countries small-sized plants are also used as mountages.

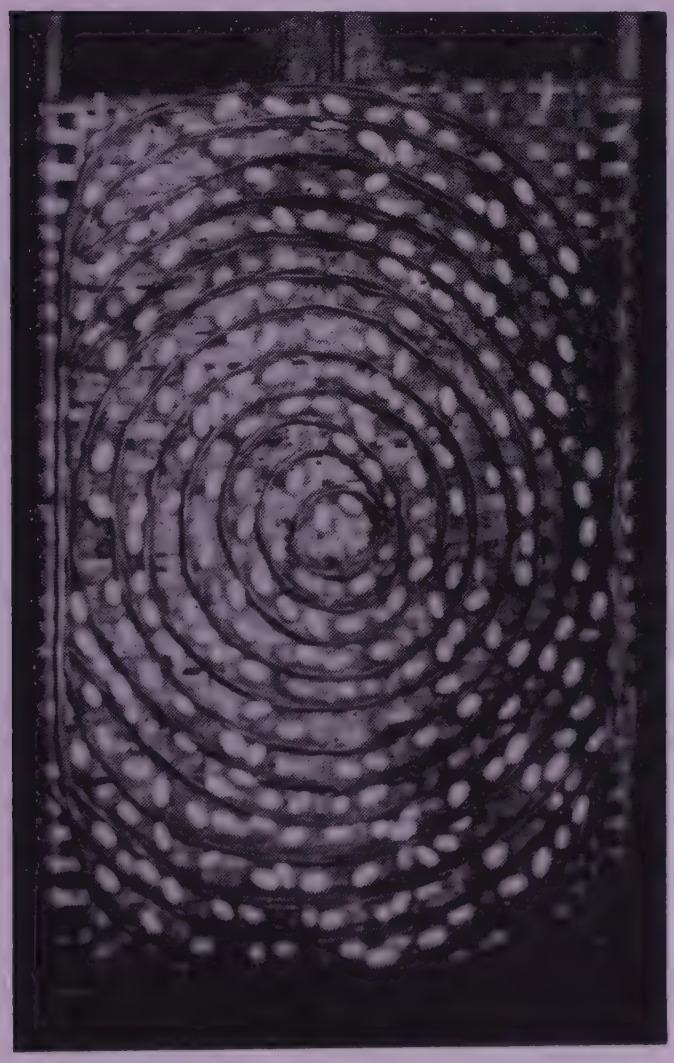


Fig. 43 — Bamboo mountage (India)

Fig. 44 — Turning cocooning frames (Japan)

Hygrometers and thermometers

These are used to record the temperature and humidity of the rearing rooms and help to maintain optimum room temperature and humidity for the healthy growth of the silkworms.

Feeding stands

These are small wooden stands 0.9 m high used for holding the trays during feeding and cleaning (Fig. 45).

Fig. 45 — Feeding stand

Other equipment

Among the other items required are feeding basins, preferably plastic, to hold chopped leaves, and buckets and basin stands etc., A sprayer is also required for disinfecting the rearing room, for spraying water on to the leaf chambers, etc. Leaf baskets made of bamboo are used for carrying the leaves from the garden to the rearing rooms.

Sanitation and preparations for rearing silkworms

The silkworms must be reared with the utmost care since they are very susceptible to disease. Bacteria, moulds and some protozoans attack the silkworms readily and any disease, once it breaks out, spreads quickly. To prevent disease, good sanitation methods and hygienic rearing technique must be meticulously followed. The rearing room and the appliances used for rearing must be thoroughly cleaned. Dust, dirt and refuse of dead larvae found in the rearing house and on the rearing appliances should be removed and the house and appliances thoroughly washed with water and dried. Afterwards the equipment and the rearing rooms should be disinfected by spraying 2–4 percent formaldehyde solution. "Formaldehyde" available commercially as a 40 percent strong solution should be diluted to the required strength and used at the rate of 800 ml to 10 m^2 (Fig. 46).

Fig. 46 — Disinfection of rearing house

Before disinfecting the rearing room all crevices and holes should be filled in and the room rendered airtight as far as possible. Ideally the room temperature should be maintained at 25°C during disinfection for quick diffusion of the formaldehyde gas. All the rearing equipment as well as the walls, ceiling and roof of the rearing room should also be sprayed. After spraying the room is kept closed for 15–20 hours, then the doors and windows are opened and the room kept open for approximately 24 hours for all traces of formaldehyde to disappear. The proper time for carrying out disinfection is two to three days prior to the actual hatching of the eggs.

(ii) Hatching, feeding, cleaning and spacing

Hatching

Hatching of silkworms generally starts early in the morning. The process of transferring the silkworms to rearing trays is called "brushing". A suitable time for brushing is about 10.00 as most of the larvae hatch by 08.00 and develop good appetites within two hours of hatching. In order to obtain uniform hatching, eggs at the blue egg stage are kept in black boxes on the day prior to hatching. In this way, the early maturing embryos are prevented from hatching and the late maturing embryos given time to develop and catch up with the early maturing ones. The next day they are exposed suddenly to diffused light so that the larvae hatch uniformly in response to the phototropic stimulus. By this method hatching of 90 per cent and over can be obtained in one day. If, however, hatching is not uniform and only 50–60 percent of the eggs hatch on the first day, brushing can be done on the following day as well. If necessary the hatched worms can be separated and kept in thin tissue paper, and stored in a refrigerator at 10°C till the next day to wait for the remaining larvae to hatch. Both the batches can then be mixed and brushed together. Newly hatched silkworms are black and hairy and look like black ants; in fact they are often referred to as "ants".

Methods of brushing

In the case of eggs prepared on egg cards, the cards with the newly hatched worms are placed in the rearing trays or boxes and tender mulberry leaves cut into small 0.5 cm squares are sprinkled over the egg cards. The hatched silkworms crawl onto the tender leaves and start feeding. Later the cards are removed and any worms still left on the card are tapped on to the rearing bed. After some time the bed is uniformly prepared in the rearing tray and the first feeding of mulberry leaves is given.

In the case of loose eggs brushing is carried out as follows: a net with small holes (mosquito netting) is spread over the box containing the hatched larvae, and mulberry leaves cut to the size indicated above are scattered over the net. Paper with small slotted holes or perforations can be used in place of mosquito netting. When the worms have crawled over to the leaves, the net with worms and leaves is transferred to the rearing tray.

Sometimes the hatched worms are brushed with a feather from the egg cards directly on to the rearing tray. This is not a desirable method as it may injure the delicate newly hatched silkworms.

After brushing the bed is prepared by collecting the worms and the mulberry leaves together by using the feather. The bed is spread uniformly using chopsticks. After about two hours of brushing the first feeding is given to the silkworms.

Prior to the first feeding, as a precaution against muscardine, the larvae may be treated with a 5 percent ceresan–lime powder.

Feeding silkworms

Silkworms are fed to satisfy their appetites and to ensure their healthy and uniform growth. It is therefore necessary to preserve the quality of leaf during feeding and to keep the rearing beds clean. In order to save mulberry leaves and labour, the feeding must correspond to the eating habits and appetite of the larvae. Feeding with too many leaves is not economical. Generally early–age silkworms eat leaves from the surface while late–age worms from the edges.

Each age of the silkworm could be conveniently divided into seven stages: (i) first feeding stage; (ii) sparse eating stage; (iii) moderate eating stage; (iv) active eating stage; (v) premoulting stage; (vi) last feeding stage; and (vii) moulting stage. The larvae have good appetites at the first feeding stage, and comparatively little appetite at the spares eating and moderate eating stages. They eat the most at the active eating stage. Afterwards their appetites increase till the last feeding stage after which the worms eat nothing more and go on to the moulting stage. The quantity of leaves supplied should be regulated according to the above feeding patterns.

Care should be taken to feed the silkworms a sufficient quantity of leaves. An insufficient supply of leaves results in irregular growth and irregularity at moult. In young-age larvae this tendency to irregularity is high. Hybrids have larger appetites than pure races and so consume more leaves.

The quantity of leaf required for rearing 50 layings or a box of 20 000 eggs at different instars is given below (in terms of actual leaf).

Univoltine and bivoltine species

Age	Kg
1st	1–2
2nd	5–6
3rd	20–25
4th	80–90
5th	450–475
Total	550–600

Multivoltine and bivoltine species in tropical areas

Age	Kg
1st	1–2
2nd	2–3
3rd	15–20
4th	35–50
5th	300–325
Total	350–400

Bed cleaning

Removing the old mulberry leaves, faecal matter of silkworms, exuviae, any dead or unhealth silkworms, etc., from the rearing bed is called bed cleaning. Accumulation of any such matter create environmental conditions detrimental to the health of silkworms. Accumulated faecal matter and ol leaves builds up humidity in the bed and favours rapid multiplication of micro-organisms. Wit fermentation setting in, the rearing bed temeprature will rise and affect the growth of worms. Periodica bed cleaning to maintain hygienic conditions is therefore indispensable in silkworm rearing.

Too frequent bed cleaning during the early stages is harmful as there is every chance of losing worm since they are minute and may be overlooked. Usually the bed is cleaned once during the first age; twic during the second age, i.e., just after first moult and again before setting for second moult; and three time during the third age, ie., just after moult, in the middle of the age and again just before settling for nex moult.

During the fourth and fifth ages, the beds should be cleaned once a day in the morning, particularly when the rearing is conducted on shelves where small shoots and plucked leaves are supplied to the worms. In the case of shoot and floor rearing where entire shoots and leaves are fed to the worms normally only one cleaning is given to the forth and the fifth age worms, i.e. after two days of feeding after the third moult, and once just prior to mounting in the fifth age.

For cleaning purposes, nets, paddy husk or charred husk are used. In the case of net cleaning, the net is spread over the bed and one or two feedings are given before the nets are lifted and transferred to a fresh cleaned tray. The worms crawl through the meshes in the net and come up to feed on the leaves on the nets. If the worms are healthy, practically all the worms will come up leaving the old leaves and litter behind on the old trays which are cleaned later. The mesh sizes of the net used for the different instars are as follows:-

1st and 2nd instars	2 mm^2
3rd instar	10 mm^2
4th and 5th instars	20 mm^2

The paddy husk or charred husk or even the cut straw used for late-age worms is spread in a thin layer over the bed prior to feeding. The worms crawl through this layer and start feeding on the fresh leaves. The worms and the leaves are removed to a cleaned tray, and the litter and old leaves left behind are thrown away.

Spacing

Provision of adequate rearing seat space is of great importance for the vigorous and full growth of silkworms. As the worms grow in weight and size, the density in the rearing bed increases and conditions of overcrowding are faced. It is, therefore, essential that the density of population in the rearing bed should be regulated and ideal rearing bed conditions ensured. Most of the troubles in silkworm rearing arise from a lack of appreciation of the importance of spacing. There is always a tendency on the part of the rearers to rear as many layings as possible within a limited space with the result that overcrowding easily occurs and frequently leads to crop losses, particulary in tropical countries.

Overcrowding of silkworms means insufficient space for the free movement and free feeding of the worms and so the larvae crawl over one another. Crowded conditions also increase accumulation of gases, heat and fermentation of faecal matter particularly during the early age when temperature and humidity in the rearing room are high. Under such unhygienic conditions, the worms do not feed freely on the leaves even thoughfresh and good quality leaves may be available in sufficient quantity. This results in unequal and unhealthy growth of larvae and often leads to crop losses.

However, if there is space beyond the optimum required, there is considerable wastage of mulberry leaves and also the labour costs for feeding increase. It will also involve avoidable unnecessary outlay on rearing equipment.

Since the silkworms grow very fast particularly in the young age, the rearing seat is also to be proportionately increased. Normally it is necessary to double or treble the space from instar to instar with the result that from the first instar to third instar, the rearing space needed increases more than eightfold. In the fourth instar, it may be found necessary to increase the space by two to three times and then in the fifth instar twice again. Thus the rearing space will have to be increased by eighty–to one–hundredfold from the time of brushing till the time of ripening of the worms for spinning.

The spacing to be provided for different ages of silkworms of 50 layings or a box of 20 000 eggs is given below:

	At the beginning of each age (m^2)	At the end of each age (m^2)
Univoltine and biovltine species:		
Age		
1st	0.2	0.8
2nd	1.0	2.0
3rd	2.0	4.5
4th	5.0	10.0
5th	10.0	20.0
Multivoltine and bivoltine species in tropical areas:		
Age		
1st	0.2	0.5
2nd	0.5	1.5
3rd	1.5	3.0
4th	3.0	9.0
5th	9.0	18.0

Spacing is generally done when the beds are cleaned. During widening of space and picking of silkworms from the beds, chop sticks should be used.

It may be necessary to provide wider spacing when the humidity and temperature are higher than optimum. Wider spacing enables free circulation of air in the rearing bed and ensures reduction in humidity and temperature in the bed.

(iii) Care at moulting

Uniform growth of silkworms of any batch depends on the care given to rearing. Among the various steps involved in the rearing of silkworms the handling of silkworms during moult is of particular importance. Silkworms under proper rearing conditions would all settle uniformly for moult and also come out of moult uniformlly. When the worms are due to moult and again when they come out of moulting they should be handled with the utmost care, as described below:

At the approach of moult, the silkworm attains its maximum body growth for that particular instar and as a result the body of the silkworm becomes stout and shiny. In relation to the size of the body, the head of the worm about the moult appears quite small and also darkish. At this time, a bed cleaning should be carried out. At the same time as the cleaning wider spacing is also provided. After the cleaning, the worms about to settle for moult are given one or two final feeds of the instar with leaves cut to a comparatively smaller size. Wider spacing and somewhat finely chopped leaves help to reduce the humidity in the bed which facilitates uniform moulting. If, however, the humidity is high, a very thin layer of lime powder may be dusted over the bed after the last feeding to keep it dry. When all the larvae have settled for moult, feeding should be stopped.

The larvae normally takes 15–30 hours to complete moulting during the different instars. After moulting the new instar larvae come out casting their old skin. At this point the head is comparatively bigger in relation to the body and it is always bigger than the head of the previous instar. The body of the worm is comparatively less shiny because of the loose skin of the new instar larvae. From these distinguishing features, the larvae still to moult or in moult and those already out of moult can be distinguished.

The first feeding of the new instar should start only after almost all the worms have come out of moult. In localities where muscardine is commonly prevalent, it is advisible to take anti-muscardine precautionary measures by dusting ceresan–lime powder on to the newly moulted worms prior to first feeding.

If any irregularity in settling for moult is observed, the late larvae may be segregated through net feeding and reared as a second batch. Similarly if a significant number of larvae should go for moult early, such early settling larvae may be separated and reared as a second batch.

As pointed out earlier, it is very important that the rearing bed be as dry as possible when the worms are in moult. This enables the silkworm to crawl out of the old moult skin easily thus helping all the worms to come out uniformally. Since the newly formed skin is thin and delicate, under more humid conditions the worms become susceptible to funal attack. Therefore, it is essential that the silkworm beds be kept as dry as possible during the moult.

(iv) Environmental conditions

Since silkworms have been domesticated for many centuries, they are by nature quite delicate and very sensitive to environmental conditions. In the commercial production of cocoon crops optimum environmental requirements ensuring maximum productivity of good quality cocoons of very high silk content are aimed at. Among the various environmental factors that influence the cocoon crops, the most important are atmospheric temperature and humidity prevailing at the time of rearing, quality and quantity of leaf supply, and the methods of rearing followed, such as feeding, cleaning, spacing, etc. Intensive studies on the behaviour of the silkworms in relation to the various environmental factors have shown that the response to all these factors varies with the different stages in the growth of the worms. Based on these responses, suitable rearing techniques have been evolved for obtaining the best results. Various environmental factors and how they affect the health and growth of silkworms are discussed below.

Temperature

Temperature plays a vital part in the growth of silkworms. Silkworms are cold-blooded animals and as such temperature will have a direct affect on the various physiological activities of their systems. With a rise in temperature various functions of the silkworms are accelerated and with a fall, their activities are slackened. With an increase in temperature the larval growth is accelerated and the larval period is shortened, while at a low temperature, growth is slow and the larval period is prolonged. The optimum temperature for normal growth in silkworms is between 20° and 28°C. Temperatures above 30°C directly affect the health of the worm. If the temperature is too low, i.e. lower than 20°C, the growth of the silkworm owing to the very low rate of Physiological functioning, is considerably retarded specially in the early stages, with the result that the worms become too weak and susceptible to disease. Young-age larvae are comparatively stronger and more resistant to high temperatures, and feed actively and grow very vigorous under higher temperature and humidity conditions. Such vigorous worms can stand better even adverse conditions in later instars.

Since the temperature is in direct correlation to the growth of the silkworms excessive fluctuations in temperature are harmful and should be avoided. The optimum temperatures for rearing silkworms of different instars are as follows:

Instars	°C
1st	26 – 28
2nd	26 – 28
3rd	24 – 26
4th	24 – 25
5th	23 – 24

The room temperature is generally low during winter and rainy days, and it should be regulated by heating with electric heaters or charcoal fires. Electric heaters are recommended since they do not emit any injurious gases; where electricity is costly or not available, properly dried charcoal can be used. If charcoal is used, it must be burnt to hot cinders in a hearth outside and then brought into the rearing room. Burning wood in a rearing room to raise the temperature should be avoided because carbon dioxide and other gases emitted are injurious to silkworms. During the summer when the temperature is high, doors and ventilators must be opened to lower the temperature by free circulation of the cool night air.

In sub-tropical regions such as Japan, the ambient temperature is always lower than the optimum required for silkworm rearing and therefore except for the summer crop, the requisite temperature has to be maintained by heating, which is comparatively easily achieved. On the other hand, in the case of tropical regions such as India, the temperature is more often above the optimum and therefore the problem is one of cooling rather than heating. Cooling generally is more difficult and more expensive.

The adverse effects of high temperatures can be overcome through proper designing of the rearing house and by ensuring adequate ventilation and free circulation of air inside the rearing house particularly during late-age worm rearing.

Humidity

As well as temperature, humidity also plays an important role in silkworm rearing. The combined effect of both temperature and humidity largely determines the satisfactory growth of the silkworms and the success of cocoon crops. The role of humidity is both direct and indirect. It influences directly the physiological functions of the silkworm. As already pointed out young-age silkworms can stand higher temperature and higher humidity conditions better than late-age worms, and under such conditions growth of the worms is also vigorous. Therefore, taking advantage of this phenomenon young-age worms are reared in comparatively higher temperature and humidity conditions to obtain the best results. In late ages, however, the worms thrive best under conditions of relatively lower temperature and lower humidity.

Indirectly humidity influences the rate of withering of the leaves in the silkworm beds. Under too dry conditions the leaves wither very fast and become unsuitable as feed and often this results in retarded growth of the larvae and also considerable wastage of leaf feed. Retarded growth of young-age larvae makes them weak and easily susceptible to disease and other adverse conditions. On the other hand too much humidity in the case of late-age worms builds up bed humidity and creates conditions that favour outbreak of disease. Therefore, different humidity conditions for the different age worms should be provided as follows:

Age	%
1st	85
2nd	85
3rd	80
4th	75
5th	70

For regulating humidity in the rearing room paraffin paper is invariably used for the rearing beds during the young-age worm rearing for raising humidity. Also, if necessary, wet foam rubber bands or paper bands may be used to increase humidity in the beds. In the late ages, if the humidity is low, sprinkling water on the floor may be found to be helpful in sub-tropical areas such as Japan where the temperature is comparatively lower. In tropical areas where the temperature usually is higher than the optimum required for the late-age worms, humidity should not be too high as both high temperature and humidity conditions canprove highly detrimental to late-age worms. If the leaves wither due to high temperature and low humidity it is better to give more water to the leaves by sprinkling them with water while they are in storage, rather than to increase humidity artificially by spinkling water inside the rearing room where the temperature is already very high.

As already pointed out, the humidity at the time of moulting in the rearing bed should be as low as possible to facilitate uniform and good moulting.

Air

Like all other animals, silkworms require fresh air for their various physiological functions. Due to the respiration of the silkworms, carbonic acid gas is released in the rearing beds and the rearing rooms, Carbon monoxide, ammonia, sulphur dioxide, etc., are also generated in the rearing rooms by the burning of charcoal to raise the room temperature. These gases are injurious to silkworms. Too many workers in a rearing room can also pollute the air. Such a poisonous atmosphere affects the health of the silkworms. The moment the poisonous gases build up in the beds and the rearing rooms beyound the tolerance limit the worms become sluggish and do not feed. Therefore, care should be taken to allow for circulation of as much fresh air as possible, through proper ventilation, so as to keep the toxic gases at a low level. Insecticides and disinfectants, such as mercurial compounds D.D.T., B.H.C. and other agricultural chemicals and tobacco are also harmful to the worms if they come in direct contact with them. Comparatively young-age larvae are more highly susceptible to these than late-age worms. Therefore, the greatest care must be taken in handling such agricultural chemicals.

Air plays an important role in regulating rearing room temperature and humidity. Free artificial circulation of air is extremely useful for bringing down high temperature and also high humidity conditions particularly in tropical regions.

Light

Silkworms are photosensitive and generally have a tendency to crawl towards dim light. They do not like either strong light or complete darkness. In complete darkness the larval period is shortened and in bright light there is a tendency towards production of heavy cocoons. Rearing in either complete darkness or in bright light leads to irregularity in growth and moulting. Larval moult is uniform when silkworms are reared in 16 hours light and the remaining period in darkness. Given the above facts it is advisable to rear silkworms in the dim light during the daytime and in the dark at night.

(v) Leaf quality

The mulberry leaf is the exclusive food of the silkworm *Bombyx mori*. It is essential that the mulberry leaves are not only in abundant supply but are also of good and suitable quality. Leaf quality has much to do with the success of silkworm rearing and the quality of the cocoons produced.

The leaf quality is influenced by various factors such as soil, pruning, fertilizers, rainfall, irrigation, etc. Leaves of mulberry trees grown on loamy soil which is more retentive of moisture, contain more water and protein while the carbohydrate and fibre content is less. The leaves also mature slowly and so are particularly suitable for rearing early-age silkworm larvae. On the other hand, mulberry leaves from trees grown in sandy or gravelly soil mature quickly and become rough and coarse, containing less moisture and protein and more carbohydrates and fibre.

As regards pruning, leaves picked from shoots following drastic pruning are softer, contain more water and less fibres, and also mature more slowly than the leaves found on shoots appearing after light pruning or from old shoots.

Similarly in the case of fertilizer application, higher doses of nitrogen fertilizer induce more vigorous growth in mulberry trees and the leaves from such trees contain more water and protein. These leaves also mature gradually and are often too soft. Application of balanced fertilizers with optimum dose of all the major elements required by the plants improves both the chemical as well as the physical properties of the leaves, and the leaves are generally good for silkworm–rearing purposes.

Under conditions of well–distributed rainfall or assured irrigation, the grwoth of the mulberry trees is vigorous and continuous and the leaves from such plants are generally richer in nutritive value, soft and succulent, and readily acceptable by the silkworms. In tropical areas mulberry leaves raised under dry conditions with limited rainfall quickly become coarse and are, therefore, not so good qualitatively.

Leaf quality is superior particularly in areas where the fluctuation in day and night temperature is high because the nutrients synthesized during the day are at least utilized during the cool night hours and, therefore, are better preserved in the leaves.

Mulberry leaves for silkworm rearing should be raised under the following ideal agronomic conditions: (i) good soil, neither too clayey nor too sandy; (ii) optimum application of balanced fertilizers; (iii) suitable cultural practices; and (iv) assured rainfall or irrigation. Under such ideal agronomical conditions the leaves are rich in protein, sugars and carbohydrates. Leaf moisture is also higher and, therefore, the leaves are succulent and soft. Such leaves are preferred by the silkworms and are also easily digested and best utilized.

From the quality angle the requirements of the young–age worms differ from those of the late–age worms. The former require comparatively tender, soft and succulent leaves having higher moisture, protein and sugar content and less starch and fibre. However, too soft leaves resulting from excessive application of nitrogenous fertilisers alone may be unsuitable for the young–age worms. On the other hand, in the case of late–age worms while no doubt the higher protein content is desirable, the leaf should not contain too much moisture. Therefore, soft and mature leaves should be preferred for feeding late–age worms.

Both for young–age and late–age worms, overmature leaves containing less moisture and more starch and fibre are not suitable as the growth of worms fed on such leaves will be retarded. It is essential that leaves for the young–age as well as the late–age silkworms should be picked at the right time for feeding depending on requirements, and should not be allowed to become overmature.

Harvesting and storage of leaves

Leaves picked from mulberry plants lose water rapidly due to withering and as a result the leaf quality is considerably affected. Leaves that lose moisture beyond a certain level are no longer relished by the silkworms which do not feed adequately on such leaves with the result that they are not nourished properly. Such worms are generally weak and become easily susceptible to disease and adverse climatic conditions which may often lead to crop losses, either partial or total, particularly in tropical zones. It is, therefore, of utmost importance that not only good quality leaves be produced but that they be harvested and preserved in as fresh a state as possible before being fed to and consumed by the silkworms.

Generally leaves harvested in the cool hours of the day — early in the morning or late in the evening — retain their freshness and succulence for a reasonable period. Therefore, it is advisable to harvest the leaves during these periods so that the moisture loss involved during the transportation of the leaves from the fields to the rearing houses is reduced to a minimum.

The leaves harvested in the cool hours of the day should be transported as quickly as possible to the rearing houses without much exposure to avoid rapid drying out of the leaves. In tropical areas where the leaves wither very fast because of high temperatures, it is advisable to collect the leaf harvests in wet gunny cloth and transport them wet to the rearing houses. This will help to prevent the fast withering of harvested leaves.

Mulberry leaves in general should be preserved in a moist cool and clean place. The tender leaves meant for young silkworms can be preserved in boxes, baskets or jars covered with clean wet cloths. In tropical areas such as India, leaves for young-age worms are usually preserved in earthern pots covered with wet cloths and placed on moist sand. Since the quantity of leaf involved is very small this method can be followed with advantage as the cool pot keeps leaves properly preserved. Leaves meant for late-age worms which are required in bulk quantities can be stored well if loosely packed and kept in a cool room with periodical sprinkling of water to prevent withering. Leaves can also be conveniently stored by covering them under polythene sheets which prevent evaporation of water from the leaves. In tropical areas where temperatures are high, leaves can be best preserved in big leaf chambers covered on all sides with wet gunny cloth.

In the dry summer months when the moisture content in the leaves themselves is low and is further lost through rapid evaporation after harvesting, it is absolutely necessary to reinforce leaf moisture by constant sprinkling of water over the leaves and to preserve them under wet gunny cloth or in leaf chambers in order to have satisfactory cocoon crops. It should be borne in mind that such preserved leaves do not carry water droplets on the surface when being fed to the silkworm in the beds.

Compared to mulberry harvests made by picking individual leaves, leaf harvests made as branches wither slowly and since therefore the quality of leaf is better preserved, so the leaf is better utilized in the case of shoot or floor rearing.

Leaf quality is also further affected by the chopping of leaves into smaller sizes for feeding the young-age worms. Chopping of leaves into smaller fragments leads to greater exposure of out surfaces and, therefore, too fine chopping should be avoided. In India people used to cut the leaves into fine shreds for feeding the newly hatched worms. This practice leads to quick drying up of the leaf shreds and consequently under-nourishment of the young-age worms.

It is, therefore, important that the leaves are not cut too small even for feeding the young-age silkworms (Fig. 47). Again, withering of leaves and the consequent loss of quality can be prevented by using paraffin paper for rearing young-age silkworms.

Proper preservation of leaves in as fresh a state as possible helps to reduce the number of feeds, which cuts down the labour cost involved in feeding the silkworms. Traditionally in India, the sericulturists feed the worms as many as six or eight times a day and once or twice late in the night as well. This drudgery of late-night feeding can be avoided by the proper preservation of leaves. Normally it is enough to have three feeds for the young-age worms and three or four feeds for the late-age worms. In tropical areas an extra feed may be found necessary.

(vi) **Rearing early-age silkworms** (Figs. 48, 49)

Different methods of rearing the early ages are practised. In all methods importance is given to maintenance of leaf quality and correct humidity and temperature in the rearing bed so that vigorous and healthy development is ensured. The two methods used at present are: 1. paraffin-paper rearing and 2. box rearing.

Fig. 47 — Chopping of leaves for feeding

Fig. 48 — II age silkworms

Fig. 49 — III age silkworms

Fig. 50 — Paraffin — paper rearing in trays

1. **Parraffin-paper rearing** (Fig. 50)

Paraffin paper is used as a bottom layer and as a cover for the rearing beds in the usual rearing trays. The object is to maintain the optimum humidity in the bed and to keep the leaves fresh for a longer period by preventing moisture loss through evaporation. Feeding is restricted to two or three times a day and so the labour required for feeding is reduced.

For young-age rearing purposes superior quality paraffin paper preferably with a melting point of 55°C should be used. Although the sheets can be used repeatedly they should not get torn or soiled through repeated use.

A sheet of paraffin paper is spread on the base of the rearing tray and the silkworms are reared on this sheet and under another. In between the sheets on all four sides of the rearing bed, strips of wet foam rubber or ordinary paper are placed to maintain the required humidity. If necessary, the edges of the top paraffin sheets may be weighted with light sticks to seal the edges for better maintenance of rearing-bed humidity.

The top paraffin-paper sheet must be removed at least 30 minutes prior to feeding so that there is adequate aeration of the bed and the accumulated toxic gasses dispelled. Once the larvae start settling for moult, it is no longer necessary to cover the bed with paraffin paper and so the bed is kept open at the top. When the worms are in moult the bed is kept quite dry. A thin layer of lime powder sprinkled over the bed will help to keep the bed dry.

With the paraffin method of rearing, particularly in humid places, there is danger of muscardine. To avoid this, a thin layer of anti-muscardine lime powder may be spread over the bed to protect the silkworms against the disease at the time of hatching, at each moult, and in the middle of each age.

2. **Box rearing**

Fig. 51 — Box rearing

Boxes or trays made of wood or plastic or galvanised iron at least 10–15 cm deep are used for box rearing. The boxes used may be with or without lids.

Rearing in boxes with lids

In this case a sheet of paraffin paper is spread over the bottom of the tray. The rearing bed is prepared over this and covered with another sheet of paraffin paper after putting in place the wet foam rubber pads. The lid is put on and the box is placed in the shelves. For rearing third instar larvae, the box is not covered with the lid. When larvae start settling for moult, the paraffin paper, wet foam pads and the box lids are removed to keep the bed dry.

Rearing in boxes without lids

Wooden boxes of uniform size and 10–15 cm deep are used. Each box is provided with a sheet of paraffin paper for the base, over which the rearing bed is prepared, wet foam rubber pads are placed on all the four sides and the bed is covered with another sheet of paraffin paper. The boxes are then piled one over the other for rearing first-age larvae. For rearing second and third-age larvae, a space of 2–3 cm for ventilation is provided between the boxes by fixing in place pieces of wood. The boxes are kept open for at least 30 minutes prior to each feeding, and completely open when larvae start settling for moult. In using this method care must be taken to disinfect the silkworms by sprinkling anti-muscardine powder because due to the high humidity of the rearing beds the larvae are subject to muscardine.

Co-operative rearing of young silkworms

Silkworms not reared properly in their young ages are prone to disease at later stages, and crops may even fail. Maintenance of optimum temperature and humidity, supply of suitable leaves, and handling of the young-age rearing with utmost care, etc., demand highly technical skills, which are not often available to the ordinary silkworm rearers. Furthermore the rearers may not be able to afford the necessary equipment to rear silkworms under the ideal conditions. In order to overcome these difficulties, co-operative rearing centres have been organised where silkworms are reared under ideal conditions and technical supervision up to the second or third moult, and the larvae in the third or fourth ages are distributed to the rearers. The co-operative young-age rearing centres are provided with ideal rearing houses with the necessary equipment and the rearings are conducted by technical experts (Fig. 52).

Fig. 52 — Co-operative rearing of young silkworms

Mulberry gardens supplying the require quality of mulberry leaves for rearing the early-age silk-worms are generally attached to co operative rearing centres.

Since the larvae are reared carefully under ideal conditions and expert technical supervision the worms are vigorous and healthy and this ensures successful crops later in the rearers' houses. Because of mass-scale rearing in co-operative rearing centres, the cost involved is reduced to the minimum and is generally charged to the rearer. The rearer is also saved much of the trouble involved in rearing young-age worms and he can handle the late-age worms for a fortnight or so without it seriously interfering with his other farm work. Generally a co-operative rearing centre can rear at a time 200-500 boxes (20,000 eggs each) up to the third moult or double that quantity up to the second moult. Today in Japan almost 90 percent of the rearings are conducted at such co-operative young-age rearing centres and this is what has contributed mainly to the sustained bumper harvests of quality cocoons.

The rearing schedule for young silkworms for 50 layings, or a box of 20 000 eggs under sub-tropical and tropical conditions is given in Tables V and VI.

Fig. 53 — IV age silkworms

Fig. 54 — V age silkworms

Table 5
Chart of Paraffin Paper Rearing of Early-Stage Silkworms under Sub-Tropical conditions (for 50 D.F.Ls — 20 000 Eggs)

Age	Temp. and Humidity	Larval Duration		Feeding						Remarks
		All Ages	Each Age	Time of day	Feeding Order	Dosage kg	Daily total kg	Size of leaves mm	Space of rearing beds m²	
1	2	3	4	5	6	7	8	9	10	11
		1st day	1st day	09.00		.040	250	5x5		Larval disinfection; brushing; place paraffin paper on and under rearing bed
				10.00	1st	.050		10x30	0.2	
				15.00	2nd	.070		"		Make rearing bed
				21.00	3rd	.090		"		
1st	27°C 85%	2nd day	2nd day	07.00	4th	.110		"	0.4	Enlarge rearing bed
				14.00	5th	.160	.550	"		
				21.00	6th	.280		"	0.8	Enlarge rearing bed
		3rd day	3rd day	07.00	7th	.280		"		
				14.00	8th	.240	.620	"		
				21.00	9th	.200		"		
		4th day	4th day	07.00	10th	.120		5x5		Cut mulberry leaves into small pieces. Going to sleep, enlarge rearing bed, remove paraffin paper
				11.00			.120		1.0	
				08.00	1st	.300		20x50	1.0	Disinfection of larval body, cover with net, first feeding, cover with paraffin paper.
		5th	1st	15.00	2nd	.450	1.300	"		
				21.00	3rd	.550		"	1.2	Bed cleaning, enlarge rearing bed

2nd	27°C 85%	6th	2nd	07.00 14.00 21.00	4th 5th 6th	.650 .800 1.000	2.450	" " "	1.6	Enlarge rearing bed, cover
		7th	3rd	07.00 11.00 17.00	7th 8th	.900 .450	1.350	" 10x30	2.0	Bed cleaning after feeding Going to sleep, enlarge rearing bed, remove paraffin paper
		8th	1st	10.00 15.00 21.00	1st 2nd 3rd	.700 .900 1.200	2.800	30x60 " "	2.0	Larval body disinfection, cover with nets, first feeding, paraffin paper only on rearing bed (not under) Bed cleaning
		9th	2nd	07.00 14.00 21.00	4th 5th 6th	1.500 1.800 2.300	5.600	" "	3.2	Enlarge rearing bed, cover with net
3rd	25°C 80%	10th	3rd	07.00 14.00 21.00	7th 8th 9th	2.300 2.500 2.700	7.500	" " "		Bed cleaning Cover with net
		11th	4th	07.00 10.00 15.00	10th 11th	1.800 800	2.600	10x30 "	4.5	Bed cleaning Going to sleep, enlarge rearing bed, remove paraffin paper

Notes: 1. Feeding dosage of mulberry leaves is shown in weight of current shoots.

2. When rearing first age and second age silkworms, paraffin paper sheets are placed both **on** and **under** the rearing bed; when rearing third age silkworms, paraffin paper sheets should be used only to cover the upper surface of the rearing bed.

3 If the rearing room for the first age silkworms is very dry, the rearing bed should be surrounded with wet folded paper or wet foam rubber pads.

Table 6
Chart of Paraffin Paper Rearing of Early-stage Silkworms Under Tropical conditions (for 50 D.F.Ls-20 000 Eggs)

Age	Temp. and Humidity	Larval Duration		Feeding						Remarks
		All Ages	Each Age	Time of day	Feeding Order	Dosage kg	Daily total kg	Size of leaves mm	Space of rearing beds m^2	
1	2	3	4	5	6	7	8	9	10	11
I				10.00	1st	0.060		5x5	0.2	
		1st	1st	16.00	2nd	0.040	0.145	10x30		
				22.00	3rd	0.045				
				06.00	4th	0.070				
	27°C			11.00	5th	0.120	0.440		0.3	Enlarge spacing in rearing bed
	85%	2nd	2nd	16.00	6th	0.130				
				22.00	7th	0.120				
				06.00	8th	0.120				
				11.00	9th	0.130				Enlarge spacing in rearing bed.
		3rd	3rd	16.00	10th	0.140	0.530		0.4.	Cut leaf to small size and enlarge spacing
				22.00	11th	0.140			0.5	
		4th	4th	06.00	12th	0.080	0.080	5x5		Worms settling for moult*
				11.00	1st	0.200		20x50		
II		5th	1st	16.00	2nd	0.250	0.750			
				22.00	3rd	0.300				Apply net for cleaning
				06.00	4th	0.400				
	27°C	6th	2nd	11.00	5th	0.500	2.050		1.2	Clean and provide space
	85%			16.00	6th	0.550				
				22.00	7th	0.600				Apply net for cleaning
		7th	3rd	06.00	8th	0.400		10x30	1.5	Clean and provide spacing.
				11.00	9th	0.200	0.600			Worms settling for moult*

III		8th	1st	16.00	1st	1.250	2.750	30x60	
				22.00	2nd	1.500			Apply net for cleaning**
		9th	2nd	06.00	3rd	1.700		2.0	Clean and provide space
				11.00	4th	2.250	9.750		
				16.00	5th	2.500			
				22.00	6th	3.300			Apply net for cleaning
	25°C 80%			06.00	7th	3.500		2.5	Clean and provide space
				11.00	8th	4.200			
		10th	3rd	16.00	9th	4.500	16.700		Apply net for cleaning
				22.00	10th	4.500		10x30 3.0	Clean and provide space. Worms settling for moult***
		11th	4th	06.00	11th	1.000	1.000		

• Remove paraffin paper cover and wet folded paper pads or foam rubber pads.

•• At 3rd instar basal sheet of paraffin paper and wet folded paper or foam rubber pads are removed. Only paraffin paper cover is used.

••• Remove paraffin cover.

(vii) **Rearing late-age silkworms** (Figs. 53, 54)

Late age worms in the fourth and fifth instars need comparatively less humid rearing conditions and also preferably a lower temperature. These are real feeding stages when the worms consume about 90 95 percent of the total feed, and therefore, adequate spacing and an adequate amount of feed should be given to these two ages. From the fourth age onward whole leaves may be given and even small chopped shoots fed to the worms. Because either whole leaves or even shoots are fed to the late age worms and so the leaves stay fresh longer, only three to four feedings need be given during the 24 hours. It is, however, advisable to give a fairly large feed as the night feed.

Methods of rearing late-age worms

Three methods of rearing are commonly known: shelf rearing, floor rearing and shoot rearing.

Shelf Rearing

Fig. 55 — Shelf rearing

Rearing of silkworms in rearing trays arranged one over the other in tiers on rearing stands is called shelf rearing. Generally rearing stands are arranged in two rows parallel to the wall, with adequate space in the centre for removing the trays and attending to the cleaning of the beds and feeding of the silkworms. Each rearing stand can accommodate up to 10 rearing trays. In India round bamboo trays 1.2 1.4m in diameter are used for rearing late-age silkworms. Under this system of rearing leaves picked individually from the mulberry trees or branches and cut to a convenient 15 cm are fed to the silkworms during final instar.

Usually three to four feedings are given a day, and nets are used for cleaning the rearing bed once a day. Since cleaning is more frequent and the trays are removed from the stands for every feeding, the amount of labour required is greater. However, shelf rearing has the advantage of accommodating more silkworms in a limited area than the other two methods. Great care should be given to proper spacing of the worms.

Floor rearing

This is another method of rearing silkworms on fixed rearing seats. The rearing seats are arranged in two to three tiers so as to accommodate as many silkworms as possible. The rearing seat should measure 1 1.5m in width and 5 7m in length according to the rearing room. The space between the tiers should be 0.6 0.8 m. Sufficient space must be provided all around the rearing seat for attending to feeding and other rearing operations. The rearing seat is usually made of wood or bamboo strips. As with shelf rearing the silkworms are fed with leaves or branches cut small. The number of feedings is three or four a day. Bed cleaning is also followed in the same way as for shelf rearing by using nets, but it is done less frequently, twice during the fourth age and three times during the fifth age. the main difference between the shelf rearing and floor rearing is that the labour required in shelf rearing to pull out the trays and put them back every time feeding and cleaning and done iseliminated. In floor rearing, which therefore, is less laborious and less labour consuming, as in the case of shelf rearing, care must be taken to provide sufficient spacing.

Fig. 56 — Shoot rearing (India)

Shoot rearing (Fig. 56)

Shoot rearing is very similar to floor rearing. Silkworms are reared on big branches in one or two tiers. The big shoots harvested from the fields are fed straight away to the worms. The rearing seats are usually 1 m wide and of any convenient length according to the measurements of the rearing house. Shoot rearing is usually on a single tier 20 cm above the ground or occasionally in two tiers with a gap between the tiers of about 1 m. Shoot rearing can be carried out indoors or outdoors. Outdoor shoot rearing is possible only when the atmospheric conditions are favourable, the temperature approximately 25°C and no interference from rain anticipated.

As mentioned above, whole shoots are supplied for every feed so the larvae keep moving upward consuming the mulberry leaves. Since the leaf supply owing to shoot feeding is distributed in three dimensions there is better aeration of the rearing beds and, therefore it is possible to have 50 per cent more worms per unit area of rearing seat as compared to the shelf or floor rearing. Cleaning is also reduced to a minimum; once in the fourth instar and once again in the fifth instar. To clean the bed, ropes of convenient length are spread parallel to each other lengthwise on the bed and under the branches and after two or three feeds, when all the worms have crawled onto new branches, the bed held by ropes is rolled into loose bundles by cutting the ropes every 2 m. After cleaning the beds the rolled up branches and the worms are transferred back on to the rearing beds and spread out again. With this method both feeding and cleaning require less attention and are, therefore, far less laborious and labour consuming.

The shoot rearing saves on labour costs which constitute a major expenditure in silkworm rearing at the fourth and fifth ages. With shoot rearing it is possible to reduce the labour force by approximately 60 percent at the fourth, and 50 percent at the fifth age. The amount of leaves required is reduced by approximately 25 percent at the fourth and 10 percent at the fifth age. Since this method is the most economical it is becoming more popular in Japan.

Under sub-tropical and tropical conditions the rearing schedule for late-age worms for 50 layings, or a box of 20 000 eggs is given in Tables VII and VIII.

Table 7

Chart of Shoot Rearing of Late-Stage Silkworms under Sub-Tropical conditions (for 50 D.F.Ls. — 20 000 Eggs)

Age	Temp and Humidity	larval Duration	Daily total kg	Mulberry leaf shape	Space of rearing beds m^2	Remarks
4th	22°C–24°C 75%	1st day	7.5	Current shoot	6.0	Disinfection of larval body, netting, first feeding (current shoots)
		2nd	20.0	Shoot	7.2	Bed cleaning immediately after waking from sleep. Enlarge rearing bed
		3rd	35.0	Shoot		
		4th	45.0	Shoot	9.0	Enlarge rearing bed
		5th	25.0	Shoot		Current shoot for feeding larvae just before going to sleep
			5.0	Current shoot		
5th	20°C–23°C 70%	1st	12.0	Shoot	9.0	Disinfection of larval body, first feeding
		2nd	45.0	Shoot	15.0	Enlarge rearing bed
		3rd	63.0	Shoot		
		4th	95.0	Shoot	12.0	Enlarge rearing bed
		5th	115.0	Shoot		
		6th	135.0	Shoot		
		7th	135.0	Shoot		
		8th	120.0	Shoot		
		9th	100.0	Shoot		Mounting starts
		10th	55.0	Shoot		

Notes: 1. Feeding 3 or 4 times a day.

2. The ratio in weight of current shoot to shoot given is 45–55:100

3. This chart is based on the atmospheric temperatures at 20°C–26°C in the day-time and 15°–22°C at night.

Table 8
Chart of Shelf Rearing of Late-Stage of Silkworms
(For 50 D.F. Ls — 20 000 Eggs)

Age	Larval Duration		Feeding						Remarks
	All Ages	Each Age	Time of day	Feeding order	Dosage kg	Daily total	Size of leaves mm	Space of rearing m²	
1	2	3	4	5	6	7	8	9	10
	12th	1st	11.00	1st	4.000		40x70		
			16.00	2nd	4.000	12.250	"		Apply net for cleaning
			22.00	3rd	4.250		"		
	13th	2nd	06.00	4th	4.250	4.250	"	5.0	Clean and provide space
			11.00	5th	7.500		Cut shoots		
			16.00	6th	7.500	23.000			
			22.00	7th	8.000				
IV									
	14th	3rd	06.00	8th	8.000				
			11.00	9th	9.000			7.0	Clean and provide space
			16.00	10th	9.500	36.500			
			22.00	11th	10.000				
	15th	4th	06.00	12th	11.000	11.000		9.0	Clean and provide space
			11.00	13th	3.000		10x30		
			16.00	14th	1.500	4.500			
	16th	1st	22.00	1st	9.000	9.000	40x70		
	17th	2nd	06.00	2nd	11.000		Shoots		
			11.00	3rd	13.000	55.000		11.0	Clean and provide space
			16.00	4th	14.000				
			22.00	5th	17.000				

18th	3rd	06.00 11:00 16.00 22.00	6th 7th 8th 9th	14.000 16.000 24.000 30.000	84.000	13.00	Clean and provide space
19th	4th	06.00 11.00 16.00 22.00	10th 11th 12th 13th	21.000 26.000 28.000 34.000	109.000	15.0	Clean and provide space
20th	5th	06.00 11.00 16.00 22.00	14th 15th 16th 17th	30.000 38.000 42.000 50.000	160.000	18.0	Clean and provide space
21st	6th	06.00 11.00 16.00 22.00	18th 19th 20th 21st	42.000 40.000 40.000 40.000	162.000	18.0	Clean the bed Spinning started
22nd		06.00 11.00 16.00 22.00	22nd 23rd 24th 25th	30.000 25.000 15.000 10.000	80.000	15.0	Mounting
23rd	8th	06.00 11.00 16.00	26th 27th 28th	10.000 5.000 5.000	20.000		Spinning completed

At 4th and 5th instars cut shoots are fed to silkworms.

In cut shoots the leaf to branch ratio is 45–55:100

Fig. 57 — Mounting of silkworms on bamboo mountages

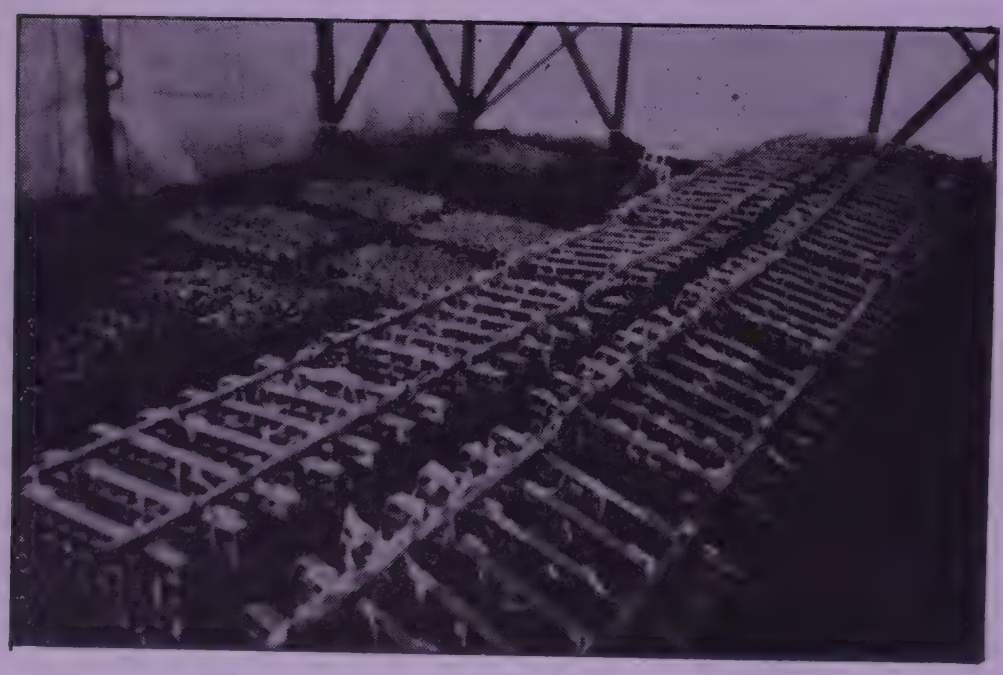


Fig. 58 — Free mounting (Japan)

(viii) **Mounting and harvesting**

Toward the close of the final larval instar the silkworm stops feeding and gets ready to build the cocoon prior to transforming itself into the pupa inside the cocoon. The feeding during the final instar may last from five to seven days in the case of multivoltine and bivoltine races in the tropical areas, and seven to nine days in the case of bivoltine and univoltine races in sub–tropical areas. With the cessation of feeding and as the stomach contents empty, the fully mature larva becomes transluscent and yellowish in appearance, which is a clear indication that the worm is fully ripe and is ready to be mounted on to mountages or cocooning frames. Such ripening larvae normally crawl towards the periphery of the rearing trays in search of suitable supports for building their cocoons. Thus the process involved in picking the ripe worms and putting them on to the suitable mountages for the spinning of cocoons is called mounting of worms (Fig. 57).

As the mature or ripe worms are mounted on the mountages they pass their last excreta in a semi-solid condition. During rains when the humidity is high, excess body moisture is also eliminated as urine. After defecating the worm starts constructing the cocoon. It anchors itself first to the mountage by oozing a very tiny droplet of silk fluid which immediately hardens and sticks to the mountage. Then by continuous movements of the head, silk fluid is excreted in minute quantities which goes on hardening to form a long continuous filament. The silkworm at first lays the foundation for the cocoon structure by weaving a preliminary web which provides the necessary foothold for the larva to spin the compact shell of the cocoon. Owing to the characteristic movements of the head of the larva the silk filament is deposited in a series of short waves or eyelets forming the figure eight and in this way layers of cocoon are built and added on to form the compact shell.

The preliminary web — the floss of the cocoon — though formed of a continuous filament is tangled and is not reelable. The floss in uni - and bivoltine races of silkworms is about 2 percent of the weight of the cocoon; in the case of multivoltine races, however it is higher, as much as 10 percent or more.

After the compact shell of the cocoon is formed the shrinking larva wraps itself in a gossamer layer and detaches itself from the shell and becomes the pupa or chrysalis. This last layer is only a body sheath of the worm and does not form part of the main shell and, like the floss layer is not reelable.

The process of spinning the cocoon takes about two to three days in the case of multivoltine varieties of silkworms and three to four days in the case of uni- and bivoltine races.

Collecting mature worms for mounting

Collecting mature silkworms and mounting them on the mountages is a laborious job. Usually the mature larvae are picked by hand by skilled labour capable of identifying the mature worms, which are collected in trays and later put on the mountages. Since the mounting is done by hand the density of the mounted worms can be controlled and the incidence of double cocoons reduced. Diseased silkworms can easily be sorted out so as to ensure that the cocoons are all healthy and of uniform quality.

In order to save the labour involved in picking mature silkworms, some simpler devices are sometimes followed such as the use of green branches or nets for collecting the worms. With the branch method, branches of green leaves are placed over the rearing bed and when the worms crawl on to them they are taken out and shaken over a mat to dislodge the worms which are later collected and put on the mountages. Similarly with the net method, nets are spread on the bed after feeding and the mature worms, which are no longer feeding, then crawl up onto the nets which are taken out and shaken off over a mat, and the worms are later mounted as with the branch method.

With the shoot-rearing method the early maturing larvae, which constitute 10-20% of the total larvae, can be picked by hand as they ripen. Later on when the remaining larvae mature more uniformly and almost simultaneously, they can be collected by shaking them off the upper layers of the mulberry branches to mats. The larvae are then mounted on mounting frames.

Method of free mounting (Fig. 58)

With this method instead of collecting the mature worms from the beds, the mountages are placed in the beds themselves and the worms carwl up onto them. Usually straw mountages or revolving mountages are used. In the U.S.S.R. brush-type local weeds are used as mountages and are placed in the rearing beds for the worms to crawl up on and spin the cocoons.

In the countries such as Japan where straw mountages are used, a thick layer of cut straw is spread over the rearing bed, the straw mountages are placed on it and the ripening worms crawl through the bed of cut straw onto the straw mountages. The mountages with worms in the process of spinning are later transferred to trays covered with sheets of newspaper which absorb the urine and faeces excreted by the larvae. Revolving mountages can also be placed over the rearing beds for free mounting of worms. These should be removed when a very thin layer of the cocoon shell has been formed and kept hanging undisturbed for completion of cocoon formation.

Density of mounting

In the case of revolving mountages density is automatically adjusted since only the number required to fill the empty blocks in the cocooning frames are mounted. Ordinarily a single frame contains about 156 blocks and 10 such frames are put together to form a unit of turning cocooning frames which can mount 1560 worms. In the Indian type of mountages, or chandrikes, the mounting should be at the rate of about 50 worms per 0.1 m^2. Overcrowding generally leads to the formation of double cocoons and also to the cocoons getting spoiled due to staining from the urine and excreta of the silkworms. Mounting done under optimum density gives more uniform and good quality cocoons.

Environmental conditions required for mounting

Maintenance of the required environmental conditions during mounting is important as it determines the quality of the cocoons spun. Silkworms under mounting normally require a comparatively drier atmosphere. Ideal conditions for good spinning are temperatures not exceeding 26^{0}C and relative humidity between 60 and 70 percent. If temperatures rise above 26^{0}C the quality of the cocoon is affected. It is particularly important that during the first 50 hours after mounting ideal conditions are maintained for cocoon spinning.

Often the liquid excreta falling from the mountages collect on the floor and build up humidity in the room. To prevent this increase in humidity absorbent material or mats, which can be changed at intervals, can be spread out underneath the cocooning frames, or the rearing room can be adequately aerated to drive out the moist air.

Harvesting of cocoons

After spinning the cocoon the larva undergoes metamorphosis inside the cocoon and becomes the pupa. Generally pupation takes place on the fourth or fifth day of spinning, in the case of bivoltines and univoltines in the temperate regions such as Japan, but in tropical areas the multivoltines pupate on the third or fourth day of spinning. The pupa when formed has a thin cuticular skin which is soft to the touch and ruptures easily if disturbed; therefore early harvesting of cocoons should be strictly avoided. In course of time the pupal skin hardens and turns dark brown and it is at this stage that cocoon can be harvested. The proper time for harvesting cocoons is on the seventh or eighth day of spinning in the case of bivoltine and univoltine races, and on the fifth day in the case of multivoltine races. Harvesting must not be unduly delayed beyond the period mentioned above lest any parasitic insects infecting the silkworm larvae emerge from the pupa and damage the cocoons.

Fig. 59 — Harvesting of Cocoons (India)

Cocoons are normally harvested by hand (Fig. 59). In the case of cardboard rotating mountages simple devices are used to separate the cocoons from the cavities in the blocks of the cocooning frames. After harvesting the cocoons are sorted: good, defective, double, pierced, stained, etc., cocoons. The good cocoons are cleaned by removing any faecal matter found on the surface and marketed at once.

Chapter-5

REARING OF WILD SILKWORMS

As mentioned in an earlier chapter, many sericigenous Lapidopterous insects produce silk cocoons, and the silk is popularly called **tasar**, **muga** or **eri** silk. Five species of silkworms of the genera *Antheraea* and *Philosamia* are exploited for commercial silk.

(i) Tasar culture

Three species of *Antheraea* are exploited for the production of wild silk known as *tasar* silk:

Antheraea mylitte, A. pernyi, A. yamamai.

A. mylitta: Reared in central and north eastern areas of India for the production of *tasar* silk. There are many regional strains of *A. mylitta* called by different local names after the prominent commercial cocoon crops. *A. mylitta* is reared on trees in the genera *Terminalia tomentosa, T. arjuna* and *Shorea robusta*. Depending on ecological conditions three types of voltinism are found in *A, mylitta*. Univoltines and bivoltines are reared in Central India, bivoltines and multivoltines in north eastern areas of India. (Fig. 60).

Fig. 60 — Tasar silkworm rearing

In addition to systematic rearings of these silk worms they also thrive naturally, and cocoons are collected in the forests by the hill tribes during the winter when the cocoons are easily seen on the leafless trees.

Emergence of moths generally takes place in May/June from cocoons spun in October/November. The rearers usually keep the necessary quantity of seed cocoons from the previous year for preparation of layings. Emergence of moths usually takes place in the evening. The males are active and couple with the females soon after emergence. The males fly long distances in search of females and so rearers often tie females onto trees so that wild-stock males may couple with the females and ensure proper mating.

After copulation for about eight hours, the females are decoupled and kept in bamboo baskets for approximately 48 hours to lay eggs which are later collected. A moth lays 150–200 eggs in two days. The eggs are oval and dorso-ventrally flattened, with two brown lines running along the periphery and are coated with a gummy substance. The larvae hatch in about 10 days after the eggs are laid.

The eggs and hatching larvae are kept in cups made of leaves which are distributed uniformly over the host trees. The hatched larvae in search of food crawl out onto the leaves of the host plant. The larval period lasts for 30–35 days in summer. It is longer in winter. Larvae pass through four moults and five instars before they become ripe for spinning. The larvae feed voraciously on the leaves and continuously defoliate the trees. In the last stages when they eat large quantities and very fast, the larvae and the branches cut for the purpose must be moved to new trees with fresh larva.

The hatched larvae are brown during the first instar and change to green at the second instar. The body carries a number of tubercles on the body which carry the setae. Morphological features make it possible to identify the different instars of the silkworm. The normal tasar silkworms at the final instar are green in colour with violet tubercles distributed over the body. (Fig. 61). A prominent brown and yellowish lateral line is visible on either side of the body, starting from the brown triangular patch on the posterior side. The tubercles are violet and carry tubercular setae. The dorsal tubercles carry brick-red shining

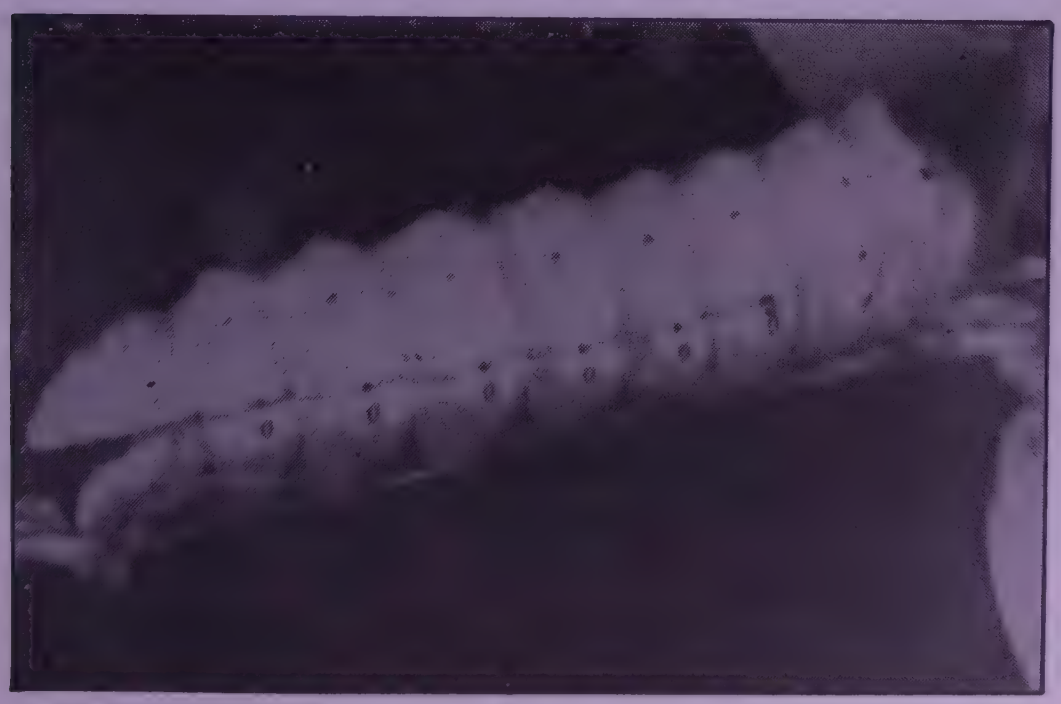


Fig. 61 — Tasar silkworm (*Antheraea mylitta*)

dorsal spots and the lateral tubercles mirror like shining lateral spots. Yellow, blue and white *tasar* silk worms are also found.

Silkworms by nature breed in the open and there is no uniformity in the growth of silkworms of the same brood. The rearer generally keeps a watch over the silkworms protecting them from predators and pests. Each larva at maturity weighs 50 60 g and measure 12.5–15 cm in length. Toward the end of the larval period the larva passes the last excreta in a semi- liquid state. After passing the last excreta the larva first spins a kind of a hammock by webbing together a few leaves of the host plant. Later it constructs a ring made of silk to attach the cocoon to the tree twig and finally it forms a peduncle which attaches the cocoon to the ring, and then the cocoon itself inside the hammock. After completing the first cocoon layer the larva passes liquid excreta inside the cocoon which gives the yellow or grey colouration to the cocoon. It takes three or four days to complete spinning the cocoon. The cocoons are then harvested from the trees by the rearers.

The cocoons of A. mylitta are compact and pendulous (Fig. 62). It is chiefly the bivoltine variety of the **tasar** worm that is used for commercial purposes. The cocoons of the bivoltine variety harvested in November/ December go into diapause at the pupal stage and the moths emerge in May/ June of the following year. The rearing of worms from eggs produced in May/ June is completed by June/ July; this is the summer crop and these cocoons do not undergo diapause. The moths emerge in 15–20 days and the layings prepared out of this crop are used for rearing the second crop during September/ October.

Fig. 62 — Tasar cocoons (*Antheraea mylitta*)

Cocoons of the summer crop are qualitatively poor with a lower silk content, but the moths lay rich layings, and, therefore, the summer crop is treated as the "seed crop" for the second crop which is really the commercial crop. The cocoons of the second crop are superior from the point of view of silk content. The cocoons of the commercial crop hibernate during the winter until the following May/June.

In the case of *A. mylitta* hetereogenity in the colour of adult moth exists. Usually the adult males vary in colour from brick-red to dark grey while the females may be yellow-grey or various shades of brown (Fig. 63, 64).

Tasar rearing is hazardous and the worms must be protected from pests and predators, such as ants, *Canthecona* bugs, wasps, *Reduiid* bugs, preying mantis, tachnid flies, birds, lizards, etc. The larvae also suffer from such disease as pebrine, flacherie, grasserie and muscardine to which they are susceptible if environmental conditions favour the outbreak of these diseases since the larvae are reared in the open under uncontrolled conditions. Depredations by pests and disease result in low cocoons yields and good harvests depend very much on vigilance of the rearer. In some parts of India trees are trimmed

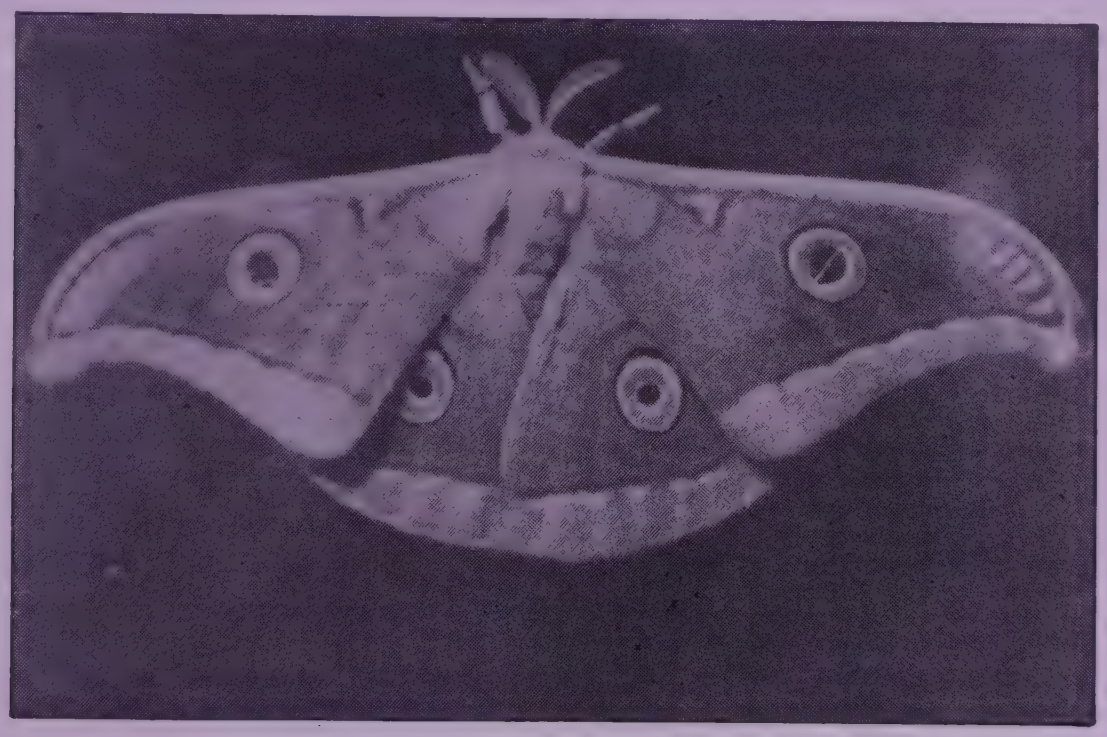


Fig. 63 — Tasar male moth

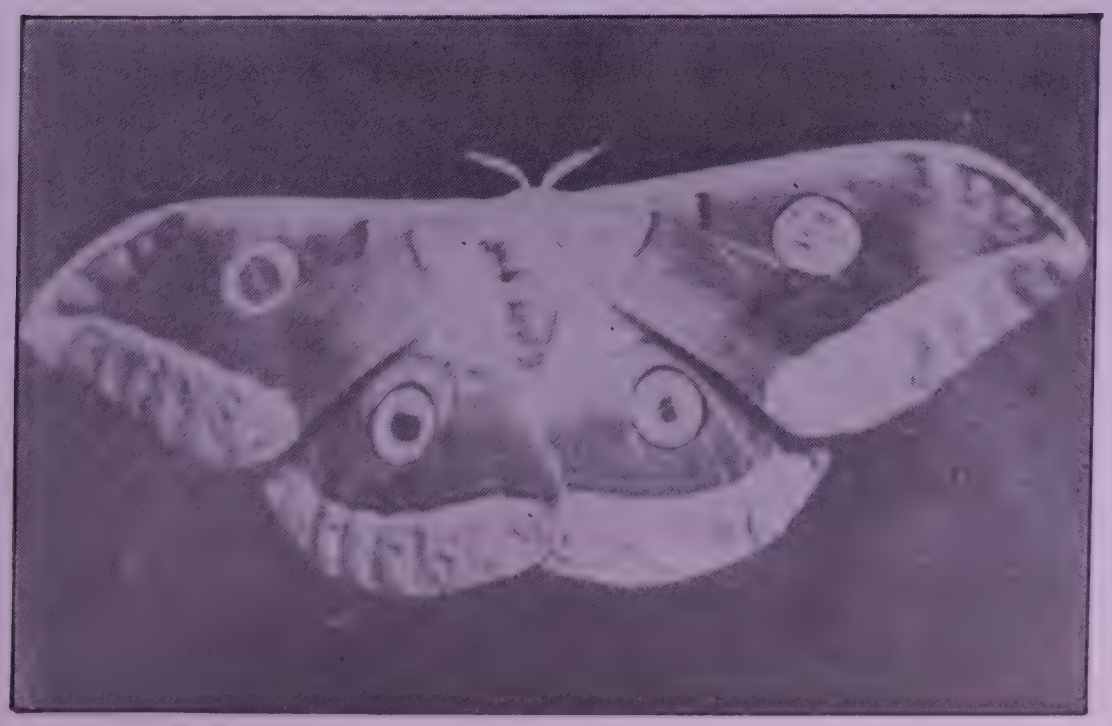


Fig. 64 — Tasar female moth

to convenient heights, so that crop pests and predators can be controlled and crop losses avoided.

Antheraea pernyi: China is the chief **tasar** silk producing country in the world. The **tasar** silkworm of China belongs to the species *Antheraea pernyi* which feeds on *Quercus* or oak trees. The insect is normally bivoltine but sometimes also univoltine. In China **tasar** silkworm rearing is practised in a systematic way. Since diapause and hibernation is at the pupal stage the cocoons of the previous season are properly preserved and kept for preparation of seed for the next crop.

Moth emergence from the cocoons usually takes place in the evening. The moths are brown in colour and have the transparent spots on the wings. The males, which have bipectinate antennae and narrow abdomens, are more active than the females. The moths couple soon after emerging. After five hours of coupling the female is isolated and allowed to lay eggs. The number of eggs in a laying varies from 150–200 eggs.

The oval eggs are coated with a gummy, dark brown substance which is without the peripheral streaks of *A. mylitta*. The egg yolk is green. The egg period lasts for about 10 days after which the larvae hatch out. The hatched larvae are black with black setae on the body. These larvae also eat the chorion soon after hatching.

In China the first and second stages the silkworms are reared indoors on oak twigs set in bottles filled with water, which keep the plants fresh till the larvae pass through the first moult. Usually the branches are changed once or twice to provide the worms with fresh leaves. After the second moult the worms are transferred to the host plants which are trained to a moderate height for the rearing of silkworms. Before transferring worms the trees are cleared of pests and predators.

The hatched larva which is black at first, changes to green after the first moult. The seatae are knobbed. The larvae pass through four moults and five instars before they are ripe for spinning cocoons. Morphologically the final stage larva of *A. pernyi* is green with violet tubercles and characteristic knobbed setae on the tubercles. The larva has a prominent lateral line on either side of the body. The head of the silkworm bears characteristic black spots distributed in a symmetrical pattern. The larval period lasts for 30–35 days. Each larva at maturity weighs 10–15 g and measures 7.5–10 cm in length.

At the end of the larval period the larva passes the last excreta which is semi-liquid. After passing the last excreta the larva spins a loose, thin ring and peduncle. The brown cocoons are compact and oval with a very thin outer layer of floss and are made of a thick silk shell. Pupation takes place within five to six days and the cocoons are harvested after seven or eight days.

The cocoons spun during the winter season emerge only the following summer. The moths from the summer crop emerge usually in 15–20 days.

A. yamamai: The Japanese **tasar** silkworm. The insect is univoltine and so rearing of the Japanese *tasar* is practiced only once a year. The silkworms are reared on oak trees *Quercus* which provide their food. The trees are trained to moderate heights to facilitate easy rearing and also to protect the silkworms from pests and predators.

The eggs are white but covered with a thick black gummy substance. Unlike the Chinese and Indian **tasar** worms, the Japanese **tasar** worms undergo diapause at the egg stage.

The hatched larvae are placed on the trees for rearing. The larvae are yellowish-green and carry smooth tubercular setae. The head of the insect is reddish-brown during the early ages becoming green at the later ages. The larvae, as they feed on oak trees, often cut the leaves partially and drop them. The larvae prefer hard oak leaves and hide behind the leaves. They thrive in dry weather. Full-grown larvae are about 10 cm in length and weigh 10–12 g. At the end of larval life they spin green cocoons which are small and compact with a small peduncle.

The moths emerge in the evening and are yellow. Copulation takes place outdoors and since the moths are easily disturbed during copulation, care should be taken to avoid disturbing them. The eggs are collected and kept for rearing the following spring.

(ii) Muga culture

The golden-yellow silk produced by the **Muga** silkworm, *Antheraea assama* is found only in Assam in India. The semi-domesticated silkworm is widely cultured in the Brahmaputra valley.

The **Muga** silkworm is multivoltine and passes through four moults and five instars. Generally 4–5 crops are raised in a year. It feeds on the leaves of several kinds of trees but mostly on som (*Machilus bombycine*) and soalu (*Litsaea polyantha*) (Fig. 65). It is semi-domesticated in the sense that only the larval stage is spent in the open and the ripening worms are brought indoors for spinning the cocoons.

The seed cocoons intended for preparation of eggs are kept in a single layer in trays to facilitate the emergence of the moths. Moths emerge from the cocoons in the evening and pair in the tray itself. Mating is allowed during the night. Next morning the mated females are separated and tied with a piece of cotton threaded to a "kharika" (a roll of straw with a hook) on which they lay the eggs. (Fig. 68).

Fig. 65 — Muga worms on branches of food plants

Fig. 68 — Pairing of muga moths on kharikas

The female moth lays about 150–250 eggs on the kharika. The eggs are big and brown. During summer the worms hatch out in the morning in about eight days. The rearers take the kharikas with the hatched worms and hang them on the the host plant. The young larvae immediately crawl up and start feeding. The young worms are yellowish with black body markings. When the leaves are exhausted the worms climb down the tree trunks and are collected on triangular bamboo sieves with long handles which are then hung on new trees (Fig. 66). A band of straw with a little sand or ash is tied round the tree

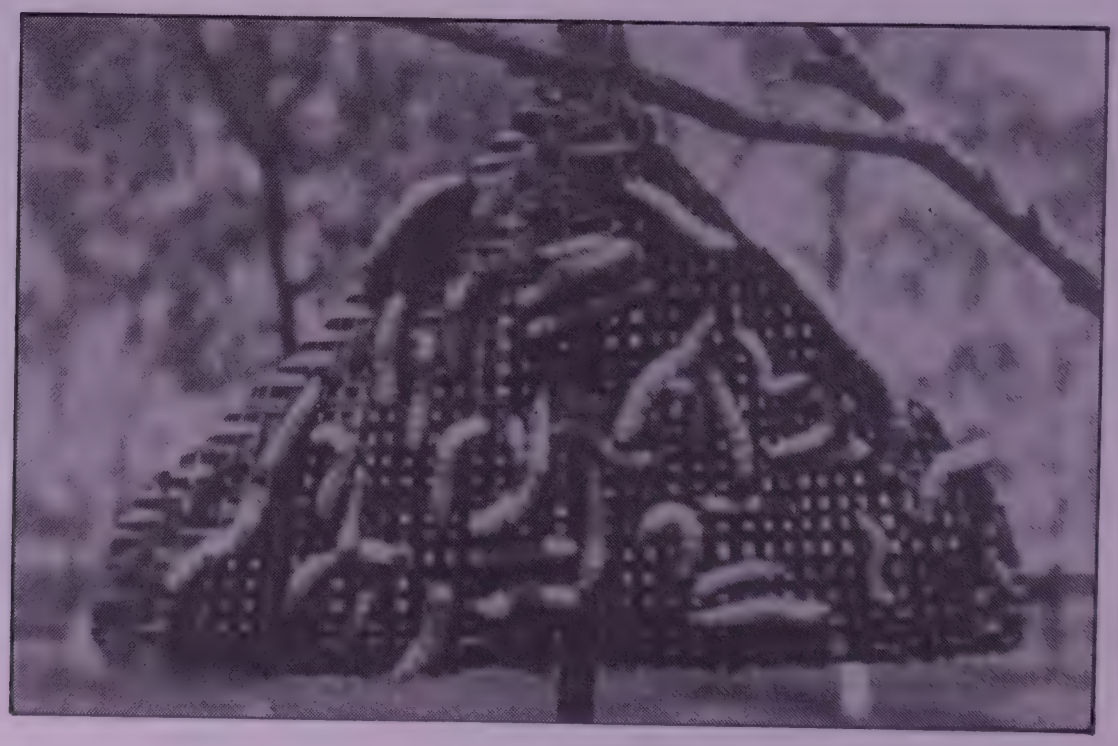


Fig. 66 — Triangular bamboo sieves for transferring muga larva to other trees

trunk 1 -1.2 m from the ground to prevent the worms climbing down onto the ground.

The larvae feed voraciously, pass through four moults and reach the mature stage. In the final stage the larva is greenish blue with prominent tubercles. The larval period lasts for 30 35 days. The ripe worms come down the trunk of the trees during the evenings and at night. They are then collected by the rearers and put in baskets containing mango twigs and leaves which act as cocoonages for the spinning of cocoons. Spinning generally takes two to three days. The **muga** cocoon is golden or light brown, 4–6 cm long and 2–3 cm broad with a rudimentary peduncle (Fig. 67).

Fig. 67 — Muga cocoons

Muga rearing like **tasar** rearing is hazardous and risky. Several kinds of insect pests and predators, lizards, birds, etc., prey on the larvae, so constant vigilance is necessary. Adverse climatic conditions can inflict heavy losses on the rearer. Pebrine, flacherie and grasserie are also prevalent among **muga** silkworms. Flacherie takes heavy toll on account of fluctuations in climatic conditions during the rearing period.

(iii) Eri culture

Eri silk or the silk of the castor silkworm is produced by *Philosamia ricini*. Assam in India is the home of the **eri** silk industry. The hilly tracts, the valleys of Brahmaputra, and rich forests of the north eastern region are characterised by heavy rainfall and humidity eminently suitable for **eri** culture. **Eri** silkworms feed mainly on the leaves of the castor–oil plant (*Ricinus communis*) from which their names comes. Their alternative food plants are *Heteropanax fragans, Manihot utilissima, Carica papaya, Ailanthus sp., Plumeria acutifolia* and many others but the **eri** worms feed mainly on castor oil plants.

The **eri** worm is multivoline and reared indoors five to six times in a year. Optimum conditions required for rearing are 24⁰–28⁰C and 85–90 percent humidity. The eggs are incubated at about 26⁰C to ensure uniform hatching. They are white and oval and are covered with a gummy substance which makes them adhere to one another. The colour of the egg changes to blue on the day prior to hatching. Generally the eggs take about 10 days to hatch. Hatching normally takes place in the morning between 07.00 and 09.00 hours. The newly hatched larvae are yellow with black segments and short setae all over the body; the full-grown mature larvae are creamy, green or blue.

The hatched larvae are fed with tender leaves and reared indoors. The growing worms undergo moult four times and have five instars. The larval period lasts for 30–35 days. Generally bundles of castor leaves are hung over the trays of **eri** larvae, which climb up and start feeding on the whole leaves. New bundles are hung up next to the old ones as soon as the old bundles are eaten and the worms crawl onto the new ones. Cleaning on the rearing bed is essential and overcrowding should be avoided. Five feedings are given during the second and third stages, three feedings in the fourth stage and four feedings in the fifth stage.

After five to seven days in the fifth stage the larvae are mature, stop feeding and start searching for a proper place to spin the cocoons. At this stage the ripe worms are picked up and put on mountages for spinning (Fig. 69). Commonly used mountages are mango leaves spread in baskets, bunches of straw or bamboo mountages or chandrikes. The ripe larvae complete spinning in two to three days. The cocoons spun by **eri** worms are open mouthed and since the silk filament is not continuous the cocoons are not reelable. The **eri** cocoons are white and elongated measuring 4–5 cm in length and 2–3 cm in width (Fig. 70).

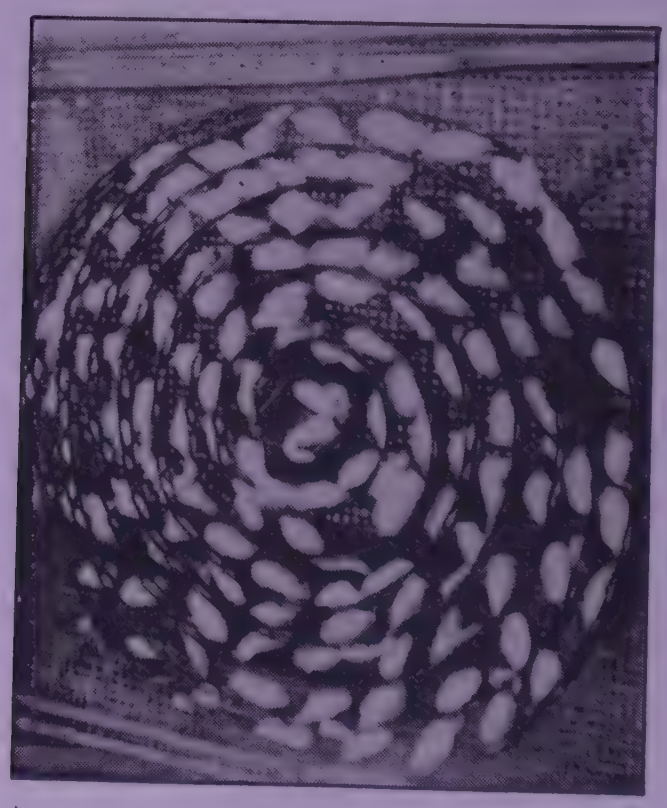


Fig. 69 — Eri cocoons spinning on mountages

Eri silkworms are generally hardy and not easily susceptible to pebrine, flacherie and grasserie although losses from these diseases do occur. Crop losses are more often caused by flacherie and grasserie than by pebrine and measures should be taken to prevent such diseases. The tachinid fly (*Tricolyga bombycis*) is one of the pests which attack eri silkworms and the rearing rooms must be protected with wire mesh.

Eri seed is produced in grainages. The seed cocoons are selected and kept in trays on stands in the grainage rooms. Moths start emerging from the cocoons in the morning and continue till midday. The male moths usually emerge earlier than the female. The moths are black with characteristic brownish lines. Mating takes place soon after emergence and it is completed by the evening. The males are then separated and discarded. Three to four hours mating is sufficient for proper fertilization. The fertilized female moth is then tied by a piece of thread to a kharika, which is hung on a wire drawn across the room (Fig. 71). A female moth lays between 300–500 eggs in the night. The optimum temperature for egg laying is between 24°C and 26°C. After they have finished laying their eggs the female moths are examined under a microscope to make sure that they are free from pebrine. The eggs are later washed in a 2 percent formalin solution, dried and kept for incubation.

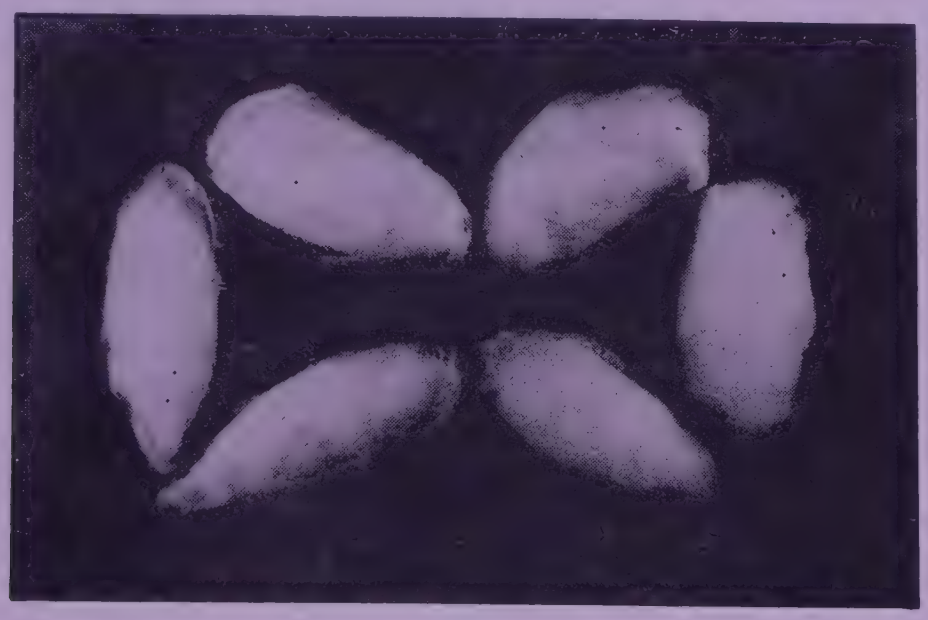


Fig. 70 — Eri cocoons

Fig. 71 — Female Eri moth laying eggs on kharikas

Chapter-6

SILKWORM DISEASES AND PESTS

Since the mulberry silkworm is a domesticated variety of silkworm, it is susceptible to disease and attack by pests and parasites. Silkworm rearing is continuous in tropical areas, and mostly seasonal in sub-tropical and temperate zones lasting from spring to early autumn, and so since silkworms are reared year after year this may possibly help the perpetuation of the disease-producing organisms, pest and parasites of silkworms.

Resistance or susceptibility to disease and pests is only comparative and there is no silkworm race totally resistant or immune to disease or pests. Many of these diseases and pests not only effect the physiological processes but the very life and existence of the silkworm itself, causing great trouble and loss to the silkworm rearers. The importance of preventing and controlling silkworm diseases and pests in order to successfully raise commercial cocoon crops cannot be over-emphasised.

This chapter gives an account of protozoan, fungal, bacterial and viral diseases, insect and non-insect pests, parasites and predators of silkworms, and measures for controlling them.

SILKWORM DISEASES

(i) Protozoan disease

Pebrine

This dreaded disease is also known as pepper disease or corpuscle disease. The name pebrine was given to the disease in 1860 by De Quatrefages because the black spots that appear on the diseased silkworms look like pepper grains. The disease was not properly understood until the researches of Louis Pasteur during the years 1865-70 brought out a method of diagnosis. Pasteur established that the disease invariably manifests itself in the mother moth though sometimes it may not be possible to detect it in the larval and pupal stages.

Causal agent and infection: The disease causing organism is the spore of *Nosema bombycis* belonging to the family Nosematidae. Pasteur observed that the disease may be transmitted through the egg, by contact with the diseased silkworms and through ingestion of contaminated food. There are two stages in the life cycle of this organism, the spore stage and the vegetative stage.

Spore stage the mature spore is oval and measures 3-4 microns by 1.5-2 microns (Fig. 72). The spore consists of:

(i) spore membrane which encloses the sporoplasm,
(ii) sporoplasm in the form of a girdle across the width of the spore,
(iii) anterior and posterior vacuoles
(iv) two nuclei in the sporoplasm
(v) polar capsule

The polar capsule is a sac-like structure that bulges out into the spore cavity from the anterior end. It is surrounded by the sporoplasm and connected at one end to the outer membrane of the spore and communicates with the outside through a small opening.

(vi) polar filament

The polar capsule encloses a spiral polar filament which is projected through the small opening mentioned above. The polar filament is more than 30 times the length of the spore (Fig. 73).

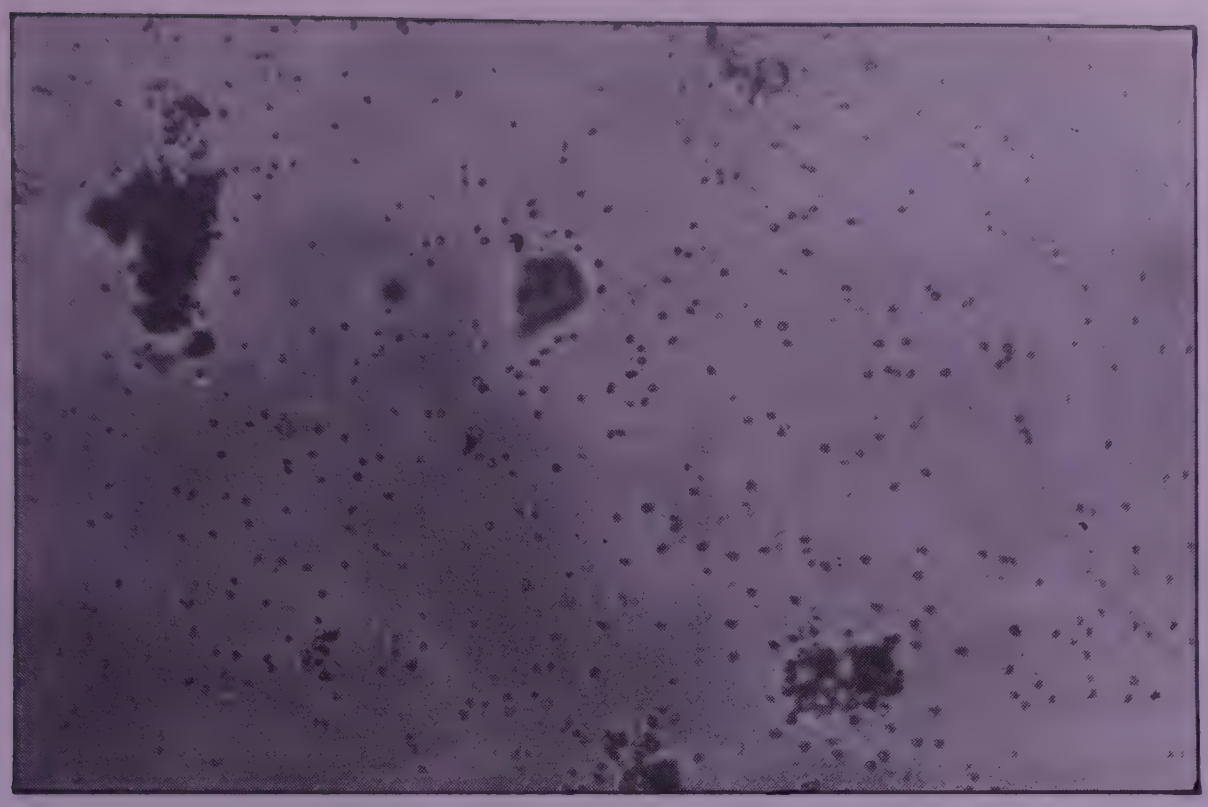


Fig. 72 — Photomicrograph of pebrine spores (*Nosema bombycis*)

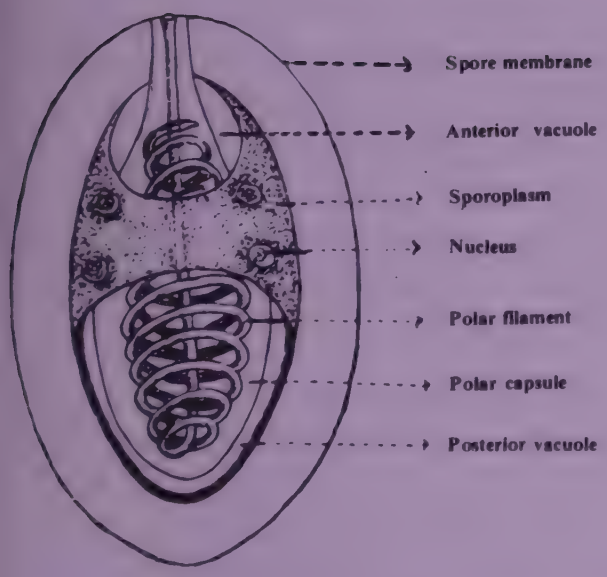
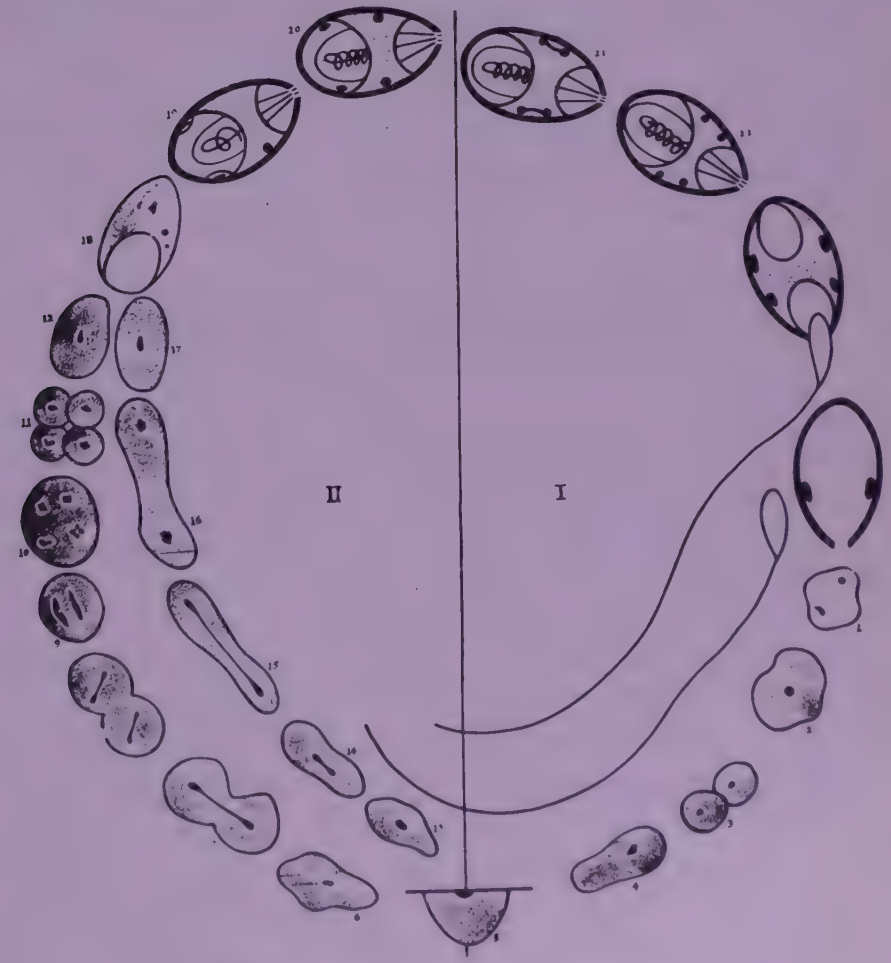


Fig. 73 — Structure of pebrine spores



Diagrammatic representation of the life cycle of Nosemabombych Naeg in the silkworm. I. Extracelluiar stages. II. Intracelluiar stages 1–4 Planonts. 5–17 Meronts. 18–20 Stages in sporulation. 21–22. Spores in midgut of new host. 23. Extrusion of polar filament. 24. Amoebula leaving spore.

Fig. 74 — Life cycle of *Nosema bombycis*

Vegetative stage (Fig. 74). — The common medium is the mulberry leaf.

The spores stick to the leaves and enter *per os* with the leaves. Soon after the spores are ingested by the silkworm, the two nuclei contained in the spores divided into four nuclei, the digestic juices act on the spores, the polar filament is extruded and soon becomes detached from the spore. The sporoplasm creeps out as an amoebula containing two nuclei and the other two nuclei left behind degenerate in the spore. The two nuclei of the amoebula soon fuse into one and an uninucleated plant is formed. The planont is globular without any membrane. These planonts pass between the epithelial cells of the insect's intestine into the hemocoele where they multiply by binary fission. They move about and soon become distributed in the various tissues of the body including the gonads, Malpighian tubes, silk glands, etc. This type of infection is known as "auto-infection".

When the planont penetrates a cell, it stops moving and soon becomes covered by a membrane. In this form is called a "meront" or "schizont". Planonts are extra cellular stages whereas meronts are intracellular stages. The meronts are larger in size than the planonts, incapable of movement, spherical or oval and ordinarily possess on a nucleus. The meront grows larger as it takes nourishment from the cell. At a certain point in its growth the meront or schizont undergoes division by binary fission, budding or multiple division. The individuals resulting from this multiplication are frequently arranged in bead-like parallel rows; ultimately the cytoplasm of the host cell is exhausted and the cell is completely filled with schizonts or meronts. This is the schizogony part of the life cycle. Then each meront becomes a sporont and finally a spore which is known as the sporogony part of the life cycle.

The main source of infection is food contaminated with spores and infection spreads within the body of the larva by auto-infection. Infection can be carried from one larva to another by the spores contained in the faeces or liberated in other ways from a diseased caterpillar or moth. The life cycle of *Nosema bombycis* is completed in a week after infection in a cold climate and in about four days in hot weather.

Symptoms: Pebrinized eggs easily become detached from the egg cards or substratum on which they are laid as they lack the adhesive gum. The eggs are laid one on top of another in lumps instead of closely side by side. Unfertilized and dead eggs are common in pebrinized layings. In extreme cases where infection is heavy, the larvae may not hatch at all.

Larvae suffering from pebrine do not show any external symptoms until the disease is far advanced. In India the appearance of black spots on the body is not very common. The disease takes a more acute form in young larvae than in adult larvae. When the disease is advanced, the larvae become sluggish and dull. They have poor appetites and generally cease to feed which results in irregular moulting and growth. Unequal development of the larvae is the most striking symptom. A tray of pebrinized larvae will have various sizes of larvae. They move slowly, moult irregularly and appear paler and more translucent than healthy larvae. When the larvae rest, their heads, instead of being held up, hand down. Affected larvae lack lustre and in the later instars,turn rusty brown and the cuticle becomes wrinkled.

An important symptom of this disease is the appearance of irregular dark brown or black spots on the body of the larvae (Fig. 75). However, this may appear in acute cases only in late instars. In such cases, the parasite gets into the hypodermal cells of the skin and as a result the hypodermal cells die here and there, exhibiting melanosis which appears as dark pepper — like spots on the integument among living parts. In many cases when the larvae are infected in the late instars, spots may not appear. A severely infected larva may die before spinning or it may spin only a poor and flimsy cocoon. Often it spits its silk and wastes it. The sure sign of the disease is the presence of numerous oval shining spores in different parts of the body of the larva, particularly in the gut.

(Fig. 75 — Pebrine-infected silkworm larva

In the pupa the abdominal area is soft and swollen and dark in colour. Black spots may be seen on the sides near the wing area. Sometimes the infected pupae do not show any symptoms.

In moths the scales rub off easily forming patches. Discoloration of scales may be seen on the abdominal area and, rarely, black round spots are seen on the abdomen and wings. Moths emerging from pebrinized cocoons have deformed wings, which do not stretch fully, and distorted antennae. The egg laying capacity is also poor. However, some of the infected moths do not show any symptoms.

Examination of the mother moth for prevention and control: The production and supply of disease-free layings by the Pasteur method is the most effective preventive method, and has indeed saved the silk industry in many countries. With Pasteur's method, the female moth is crushed after ovi position and the fluid examined microscopically for the presence of pebrine spores. Eggs from moths showing such spores are destroyed. Only the eggs from disease-free moths are retained for rearing. By adopting the preventive step. It also possible to eradicate the disease if prevalent in any area.

General preventive measures: Surface sterilization of disease-free layings should be carried out by dipping the egg cards in a 2 percent formalin solution for a few minutes and then washing in running water. Other general preventive measures are maintenance of strict sanitation, hygienic rearing, frequent and careful inspection of stocks for signs of infection, destruction of diseased material, and disinfection of rearing rooms and appliances.

The use of disinfectants is important not only to get rid of any infection which may be present in rearing rooms and appliances, but also as a prophylactic. Dead eggs, dead larvae, dead pupae in the cocoon, dead moths, excrement of larvae from infected trays, exuviae of infected larvae and other possible sources of infection such as contaminated litter should be removed and destroyed.

Disinfectants and disinfection: The most commonly used disinfectants after the rearing is over are formalin and bleacing powder. Bleaching powder is used in Japan for disinfection of rearing rooms which cannot be made air-tight. A 2 percent solution is strong enough for disinfection and is the simplest and the most economical germicide. This can be prepared by mixing one part of 40 percent formalin with 19 parts of water. It is better to use warm water for the preparation of the solution. The rearing, room, trays, mountages, stands and other rearing appliances should be thoroughly washed with water before disinfection. Prior to disinfection, the rearing room should be closed and care must be taken to seal the holes and cracks in the windows and doors of the rearing rooms by pasting paper over them in order to avoid escape of formalin vapour. The temperature of the rearing room should not be below 25°C at the time of disinfection and for six hours afterwards, therefore disinfection is usually done before noon. The pebrine spores are destroyed when they come into direct contact with the formalin solution. Care must be taken to protect the eyes, nose and mouth because formalin vapour is extremely irritating to the mucous membrane.

800 ml of 2 percent formalin is needed to disinfect approximately 9 m^2 and approximately another 250 ml to disinfect 18 m^2 of the rearing appliances if they are to be disinfected in the same room. The rearing rooms must be kept completely closed for about one day after the spraying of the disinfectant. The next day, the rooms are aerated completely for one day and then sprayed or washed with water to remove the smell of formalin and to maintain cleanliness.

Rearing resistant races: The resistance to pebrine differs according to the race. It has been claimed that the Japanese species of silkworms have a higher resistance than most other races; that European races are susceptible; and that Chinese and certain indigenous Indian species are comparatively resistant. Search for a totally resistant race has been unsuccessful so far.

(ii) Bacterial diseases

Flacherie

In early literature on insect pathology, the word "flacherie", which is one of the most general and common of the descriptive terms, was used to describe the flaccid condition seen in the silkworm, *Bombyx mori,* ailing from all sorts of dysenteries. Even now this term is widely used to describe many different diseases.

Various theroies have been put forward regarding the cause of flacherie. Pasteur separated flacherie from other silkworm diseases and attributed the disease to microbial or infectious causes. According to him, owing to the extremely rapid multiplication of a large number of certain kinds of bacteria in the intestine the digestive functions of the gut were adversely affected giving rise to the symptoms typifying the disease.

Other attributed causes are: (i) high temperature, high humidity and bad ventilation; (ii) bad leaves, i.e. dirty coarse leaf, leaf not suited to the age of the larvae, wet and fermented leaf, etc; (iii) over feeding; (iv) decreased alkalinity of the gut; and (v) over-crowding, etc.

A large number of bacteria from mulberry silkworms or from mulberry leaves, including *Streptococcus bombycis* and *Streptococcus pastorianus,* have been isolated but these were not found to be pathogenic under ordinary circumstances but only when the temperature was high.

The fact that the disease does not occur when nutrition and weather conditions are favourable and does when they are not gives rise to a theory that this is a type of physiological disease and that bacteria are not involved.

Of late it has become clear that the aetiology of flacherie is far more complex that Pasteur and other earlier investigators of this disease supposed. According to some workers it is believed that the exciting agent of true flacherie is an ultra virus and that *Bacillus bombycis* is a secondary invader.

On the basis of the latest information available, flacherie is now classified into five types depending on causal agent and symptoms: bacterial diseases of digestive organs; septicemia; sotto disease; cytoplamic polyhedrosis, and infectious flacherie. Though the Japanese workers have placed gattine with bacterial disease of the digestive organs, Steinhaus has placed it with virus infections. Cytoplasmic polyhedrosis, infectious flacherie, gattine and grasserie are discussed under *Virus Diseases.*

Bacterial diseases of the digestive organs

Causal agent and infection: Various theories have been advanced as to the cause of these diseases: the bacterial theory, the non-bacterial theory and the intermediate theory. The last theory is widely accepted. According to this theory, silkworms become weak on or after hatching, then their metabolism becomes inactive, causing imbalance of functions. As the sterilizing power of the digestive fluid weakens, the bacteria devoured together with mulberry leaf multiply in the digestive tract and take nutrition from the body of the silkworm, destroying the membranous tissue of the intestine. The following major bacteria have been found to be associated with the progress of the disease: (i) initial infection stage: *Streptococci:* (ii) final stage (near death): *Coli* such as bacillus; and (iii) moribund stage or corpse: *Proteus* such as bacteria.

Symptoms: The symptoms are not always uniform and vary according to the time of occurrance, the kind of bacteria multiplying in the digestive organ, the race of the silkworm and other conditions. The general symptoms are: the larva loses appetite, becomes sluggish and grow slowly. Inelasticity of the skin and softening of the body are also observed. These are the symptoms common to all flacherie but the time of infection of silkworms and the progress of the disease show symptoms characteristic of each type of the disease:

(a) shrinking after moulting: the larva does not feed after moulting and its body shrinks;

(b) shrinking disease: the body of the larva shrinks since it does not feed;

(c) diarrhoea; this suddenly afflicts the silkworms in the fourth and fifth instars, especially in the latter, causing soft excrements of irregular shape. In the latter case, the excrements come out in beads mingled with membrane of the intestine;

(d) vomiting disease: diarrhoea and vomiting of fluid are observed. The body softens, putrifies and shrinks as time passes.

In most cases the body becomes black (Fig. 76) but sometimes it turns red owing to the presence of *Bacillus prodigiosus* or green because of *Bacillus pyocyaneus.* Mixed propagation of a few bacteria may show some other colours.

Fig. 76 — Flacherie — affected silkworms

Control: (1) The first and foremost requisite is to raise healthy and strong silkworms since the primary cause is the weakness of the silkworms. (2) Proper incubation of eggs; the silkworms become weak if the eggs are incubated at higher temperatures or greater dryness than approximately 60 percent of relative humidity. Temperature and humidity should be maintained at $22^0 - 25^0$C and 80–85 percent respectively. (3) Selection of suitable race: it is essential to select a race that is sturdy and resistant to adverse conditions for summer and autumn rearing. (4) Feeding of good quality leaf; the health and development of the silkworm is closely related to the quality and quantity of the leaf fed. It is essential to feed plenty of high–quality mulberry leaves to avoid flacherie. Leaves grown in too little sunshine, dry weather, shade, or with lack of fertilizer, or muddy, dusty, withered leaves, etc, are poor in food value, and detrimental to the health of the larvae, particularly in the early larval stages.

Septicemia

Causal agent: Penetration and multiplication of certain kinds of bacteria in the haemolymph cause septicemia. The principal pathogenic bacteria are large and small bacilli, streptococci, staphylococci, etc. Infection is through an injury or wound in the skin. Pupae or moths which do not feed, are also affected with septicemia. Even with bacterial diseases of the digestive organs, bacteria may sometimes penetrate into the body fluid through the membranous cells of the alimentary canal towards the final stage of the disease and cause septicemia.

Symptoms: They vary depending on the kind of bacteria. When a silkworm is infected with more than one kind of bacteria, the symptoms are determined by the predominently propagated one. As the disease advances,the pro–legs lose the capacity to clasp and the worm dies. The body of a diseased larvae does not differ much in appearance to that of a healthy larva until it dies, but when the larvae vomit fluid, the body

shrinks. Soft and liquid like excrements irregular in shape may be found. Towards death the excrements become brown or dark brown. Depending upon the kind of bacteria present, the colour of the dead body also varies. In many cases black or greyish black colours may be observed. But colours such as dark brown (*Proteus* such as *Bascillus*) red (*Bacillus prodigiosus*) green (*Bacillus pyocyaneus*) light yellow, etc., are also to be observed. Occasionally, many small brown or dark brown spots appear on the skin. Depending on the kind of bacterial infections, the corpse may or may not emit a foul odour. In general, the fore intestine part of the body may be swollen and the posterior part shrunken in dead larvae. The disease occurs in a similar manner as regards colour, progress and odour in pupae and moths.

Control: Irrespective of the health of the silkworm the disease is transmitted mainly through an injury or wound. Hence the infected silkworms should be treated as for any other infectious disease. The affected silkworms should be isolated from the healthy ones as soon as possible and destroyed by burning or burying deep in the soil. General disinfection of rearing rooms and rearing appliances with a 2 percent formalin must be carried out after rearing is over.

Sotto disease

Pathogen and infection: *Bacillus sotto* Ishiwata (*Bascillus thuringiensis* var. sotto) or a large bacillus is involved in this disease. It produces a toxic substance and the disease is a toxicosis. The toxin produced is dissolved in the alkaline digestive fluid and absorbed through the gastric wall. It affects the nerve centres, causing spasm and paralysis.

Symptoms: The symptoms are lack of appetite, sluggishness, lack of skin tension followed by shrinkage of the body, diarrhoea, complicationof both shrinkage and diarrhoea, constipation, loss of clasping power of prolegs followed by death. The body of the insect becomes black shortly after death. The time from initial infection to death is shorter when temperature and humidity are high. The corpse becomes dark brown and the inner organs of the body are liquified. If the skin is cracked, a black foul–smelling liquid oozes out.

Control: *Bacillus sotto* is found in silkworms killed by this bacteria, in diseased larvae in mulberry leaves and even in the air and water. Since this disease is a toxicosis caused by swallowing bacterial toxin, regardless of the health of larva, prevention of swallowing of the toxic substance by the larva is the primary step in controlling this disease. Diseased silkworms must be removed from the healthy ones and destroyed. As usual the rearing rooms and rearing equipment must be thoroughly disinfected before starting the next rearing.

Court

This disease is known as court in Europe and rangi in India. It is a minor bacterial disease. The causalagent is the bacterium *Serratia marcescens* Bizio (Bacillus prodigiosus Fluigge). These bacteria are short, spherical rods, measuring 0.5 x 0.6 to 1 micron and occur singly or in small chains. They are motile with peritrichous flagella, and gram negative. The genus *Serratia* usually produces a characteristic red or pink pigment, although white to rose strains also occur.

Infection: The bacterium almost always produces a fatal infection when inoculated into the silkworm, but when introduced with the insects' food, it frequently does not kill the host. When ingested, it is pathogenic to varying degrees according to the stage of the larvae. The percentage of mortality is higher when the insect is nearer to the pupal stage.

Symptoms: The disease is identified by the crimson–red colour of the affected silkworm larvae and pupae at the time of death or after death. The affected larva also turns flaccid. Normally only the larva and pupa are affected.

Control: This bacterium occurs commonly in nature, and individual silkworms are sometimes found infected with it. However, clean, hygienic rearing, careful handling of the silkworms without causing injury, isolation and destruction of diseased individuals will help to control this disease. Extensive epizootics, however, are apparently very rare. Silkworms showing symptoms of this disease should not be used for seed preparation. General disinfection of the rearing rooms and rearing appliances also must be carried out with a 2 percent formalin solution immediately after rearing or before the next rearing.

(iii) Virus diseases

Virus diseases found in silkworms are grasserie or nuclear polyhedrosis, cytoplasmic polyhedrosis, infectious flacherie and gattine.

Grasserie

This disease is also known as jaundice or nucelar polyhedrosis. Jaundice indicates the yellowish colour of the diseased insect.

Causal agent: Among the various amicorbial factors once attributed to its cause were such things as poor nourishment, unsuitable leaves, uneven temperatures, damp air, poor ventilation and excessive moisture. Now we know that some of these conditions, though not the specific cause of the disease do influence the course of infection and constitute important predisposing factors. Microbial agents were also suspected of being responsible for the disease. But on the basis of our present knowledge it is concluded that grasserie of silkworms is caused by the *Borrelina* virus, which is a parasite principally in the nuclei of certain cells. It initiates the morbid process that ends in the elaboration of polyhedral bodies. The grasserie virus is contained in vast quantities in the supernatant haemolymph fluid and in the polyhedral bodies. Polyhedra vary from 0.5–15 microns in diameter. Their shape also varies, they usually have five or eight facets, although polyhedra of six facets are the more common. The virus constitutes only about 3–5 percent of the polyhedron. The virus may occur as bundles of small rod–shaped particles which at times maybe seen to separate from each other. They are about 30–50 millimicrons in diameter (including the developmental membrane) and about 200–400 millimicrons in length and are incorporated within the structure of the polyhedron. The nucleic acid of the nuclear polyhedrosis virus in the silkworm is DNA.

Infection: It is believed that the disease begins with the digestion of infectious material (polyhedra or free virus) into the alimentary tract of the insect. It has been assumed that the alkaline reaction of the silkworm gut, as well as certain enzymes present there, dissolve the polyhedra, releasing the virus which then passes through the intestinal wall into the body cavity of the insect, and invades the cells of the susceptible tissues.

The polyhedral bodies are formed in the nuclei of adipose tissue, tracheal membranes, dermal cells and blood cells, but generally polyhedra are not formed in glands of nerves. However, the formation of polyhedra in the middle and posterior portions of the silk glands has been noticed.

There is a close relationship between the atmospheric temperature and the occurrence of this disease. The disease may be induced when low temperature (5°C for 24 hours) or high temperature (50°C for 10 minutes) treatment is applied to the larvae immediately after moulting. Surface contamination of the silkworm eggs is possible and can be a source of infection. It has been shown that the grasserie virus reproduces very actively when the silkworm is weak through vitamin deficiency.

Symptoms: As the disease advances, appetite decreases and skin tension is lost. Usually five to seven days after infection, the intersegmental membranes of the body become swollen and the skin becomes shiny. The diseased larva in the final stages of attack shows pronounced swellings at the intersegments giving the larva the appearance of a bamboo cane with distinct nodes (Fig. 77).

Fig. 77 — Grasserie — affected silkworm showing swelling of intersegments

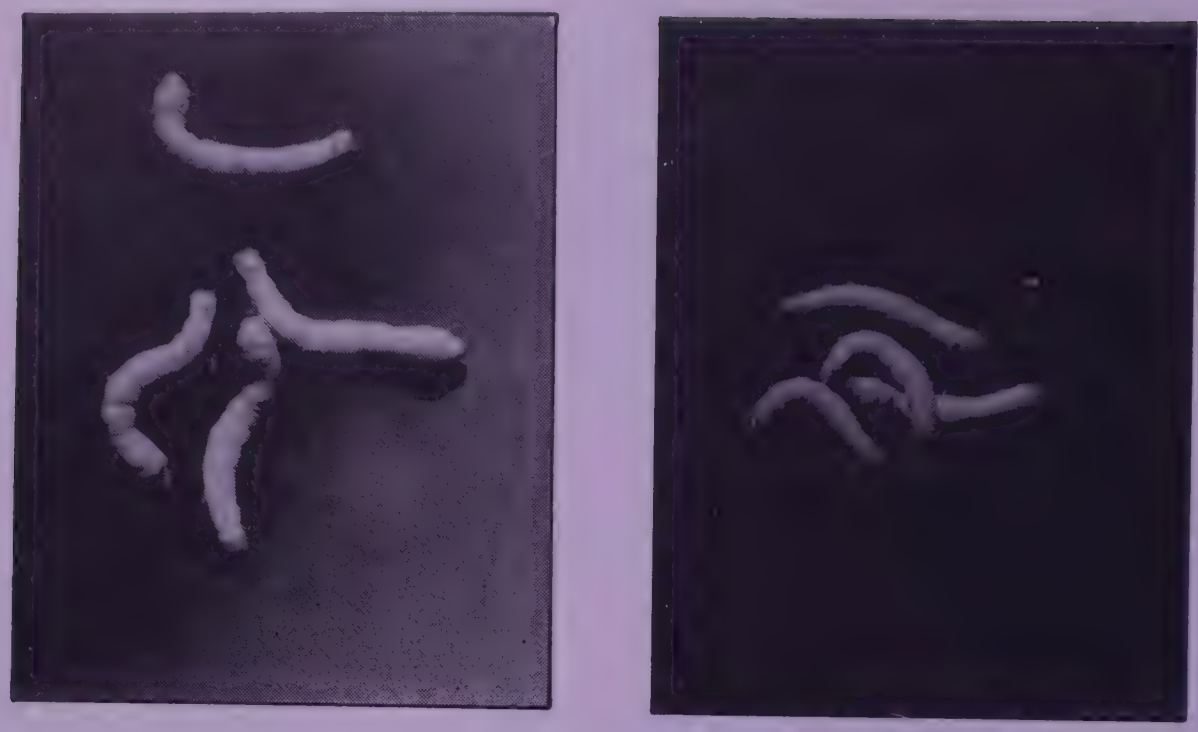


Fig. 78 — Left: normalsilkworms Right: grasserie-affected silkworms

The larva becomes restless and impatient.The colour changes to light yellow and the normally clear haemolymph becomes turbid. The integument becomes fragile and when ruptured, a milky haemolymph flows out. In the haemolymph of infected larva numerous polyhedral bodies are observed. The adipose tissue which disintegrates as a result of the attack is released as a milky fluid which mixes with the haemolymph. If the disease occurs just before moulting, the period when it is most likely to occur in the earlier stages, the larva does not go into moult earlier (Fig. 78).

In fact many victims do not moult at all.As the disease advances, the larvae are excited, crawl aimlessly and fall off the rearing tray onto the floor where they crawl in a circle and die. The period from the swelling of the inter-segmental membranes to death is relatively short, from several hours to less than a day. A ripe larva attacked with grasserie may waste its silk or it may spin a flimsy cocoon and die before or after pupa formation.

During the greater part of incubation period of the virus, no external change is observed in the pupa. But toward the end, the skin is easily ruptured on handling as the pupal body is almost homogenized by that time. Sometimes black markings are observed on the body about the time of death.

Control: Rearing the larva under hygienic conditions, avoiding unsuitable leaves, proper ventilation and spacing, timely picking out of and destroying of affected worms, are some of the precautionary measures that can be followed. The virus can also infect the silkworm through wounds and so the silkworms should be handled carefully so as not to cause any injuries. Another cause of the disease is reported to be physiological disturbance under unfavourable conditions. So extremely low or high temperatures in the rearing room must be avoided during the rearing period. Great care should be taken in removing the sick and dead caterpillars , as their skin is so fragile that rough handling will cause it to break and liberate the infectious material. The diseased ones may be easily separated by using a net as they are left behind with litter and can be easily destroyed.

Polyhedral bodies retain their infectivity for a long time under dry conditions, but this infectivity is lost in 30 minutes at 70°C, and in three minutes at 100°C, therefore rearing tools and appliances should be sterilized with steam or hot water. The rearing room and rearing appliances can also be disinfected with formalin or high-power bleaching powder in order to inactivate the polyhedral bodies.

A 1 percent caustic soda solution or a 2 percent formalin solution can be used for dipping the egg boards for 2 minutes for surface sterilization. The egg cards should then be rinsed in running water for a few minutes.

Cytoplasmic polyedrosis

This is also a virus disease and sometimes reported to be the cause of some of the so-called flacherie.

Causal agent: The causal agent is the *Smithia* virus. The polyhedra are formed in the cytoplasm of the cylindrical cells of the mid-gut. The virus particles of the cytoplasmic polyhedra are spherical and measures 30-60 millimicrons. There are two types of cytoplasmic polyhedrosis in the silkworm, one producing hexagonal polyhedra and the other tetragonal; the latter is supposed to be a mutant of the former. The size of the polyhedra in silkworms varies greatly and the tetragonal cytoplasmic polyhedra may measure from 3-10 microns. The nucleic acid of the cytoplasmic polyhedrosis virus is RNA.

Infection: Infection can take place through the oral cavity and by induction. As polyhedra are freely released in the excrements, infection in the rearing trays is more common. In Japan the appearance of cytoplasmic polyhedrosis is relatively low in the spring, and high in the summer and autumn. This is said to be due to differences in mulberry leaf quality. Outbreak of cytoplasmic polyhedrosis is more frequent in autumn.

Symptoms: The symptoms of silkworms affected with nuclear and cytoplasmic polyhedrosis differ considerably because of the different sites of virus multiplication. In the case of cytoplasmic polyhedrosis, affected larvae appear like those affected with flacherie. They lose appetite and lag behind normal larvae in their development. The head is sometimes disproportionately large. Polyhedra

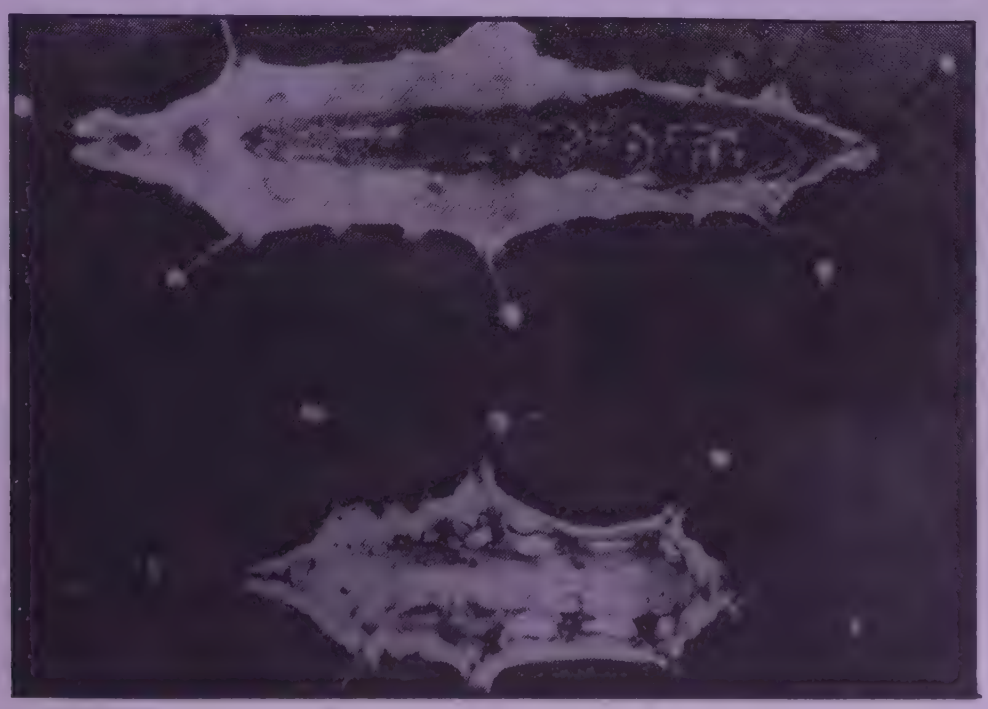


Fig. 79 — Above: gut of normal silkworm
Below: gut of cytoplasmic polyhedrosis-affected silkworm

developing in the gut can frequently be observed through the dorsal integument as a pale yellow or whitish area. The infected larva passes soft whitish excrements. The most important symptom is whitening of the mid-gut and this is clearly seen on dissection (Fig. 79). The whitening starts from the posterior part of the mid-gut and advances forward. In severe infections, the whole midgut is whitened. Many polyhedra can be seen in the cytoplasm of the cylindrical cells of the mid-gut on histological examination through a powerful microscope. In the late stage of the disease the cells are broken and the polyhedra are frequently regurgitated, or voided in large quantities with the faeces. Sometimes rectal protrusion also occurs (Fig. 80).

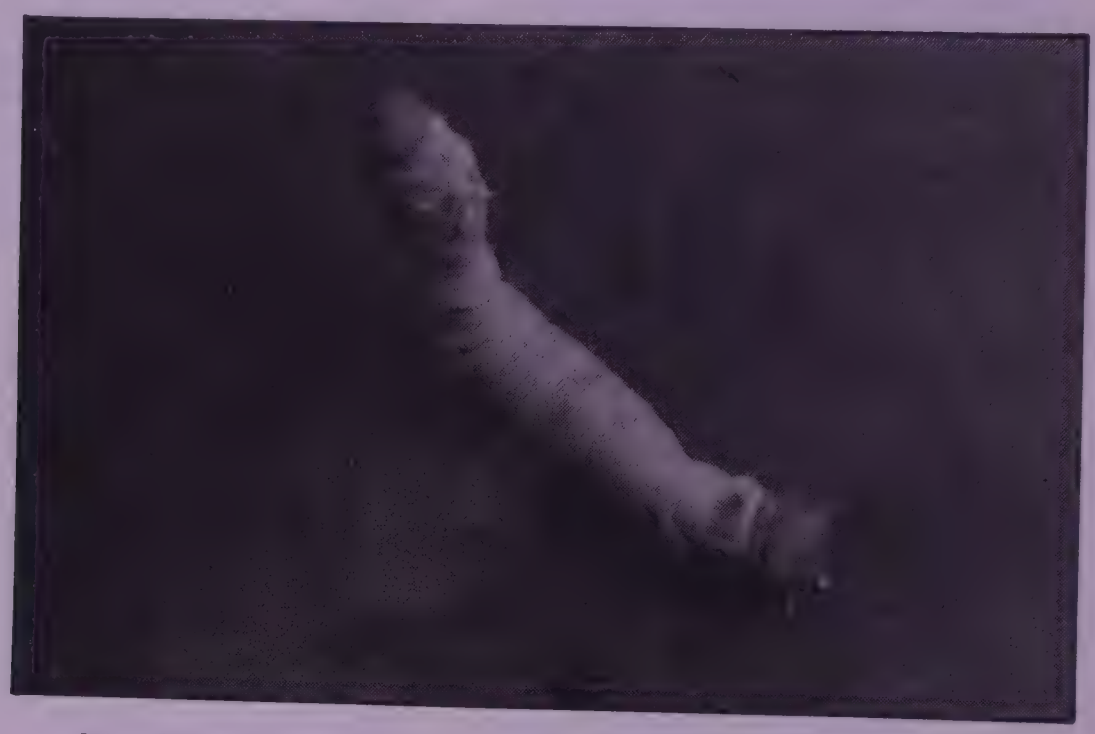


Fig. 80 — Rectal protrusion in cytoplasmic polyhedrosis

Control: The control measures are the same as for grasserie.

Infectious flacherie

Causal agent: A virus known as *Morator* virus has been isolated from the silkworm, *Bombyx mori* infected with flacherie. It is believed that this virus is free in the tissues and is not occluded in a crystal as in polyhedrosis. The virus particles are about 27 millimicrons in diameter.

Infection: Infection takes place mainly through the oral cavity. Soon after infection, the virus is liberated into the excrements, and secondary infection takes place in a rearing. Earlier instars are easily infected. Whether this disease can be caused by induction is not clear. Usually the latent period is seven to twelve days.

Symptoms: The infected silkworm shows various symptoms as in the so-called flacherie. Diagnosis on the basis of outward appearance or autopsy is not possible. One of the methods of diagnosis is by histochemical techniques. With this method, the histochemical changes of mid-gut tissue are examined under a microscope. Following another method the virus is separated from the homogenate of the infected silkworms and given to healthy silkworms to see whether they are infected.

Control: The control measures are the same as for grasserie.

Gattine

In literature the names Clairette and Luzette once referred to the same disease. It is also known as the disease of the clear heads.

Causal agent and infection: Gattine appears to be caused by a submicroscopic virus to which the bacterium *Streptococcus bombycia* is a secondary invader. At the beginning of the disease, when nuclear lesions are first discrenible in the mid-gut epithelium the intestinal contents of the insect are practically devoid of micro-organisms which, however multiply rapidly and cause the characteristic symptoms of the disease. Certain of the histopathological lesions produced in the intestinal epithelium of silkworms are caused by the virus alone.The streptococci infection is nearly always manifested after the appearance of the characteristic nuclear lesions in the midgut epithelium.

Streptococcus bombycis plays a significant part in the development of gattine, although it is not the principal cause. In the gettine virus, the characteristic tissue lesions are not found, nor is the syndrome of gattine complete.

The virus can retain its potency in the dust of the rearing cages for long periods of time which makes this source of infection a serious one. If an infective dosage of the causative virus is ingested, the disease will result. Infection may also occur through the eggs as there is evidence that the virus may pass through the eggs.

Symptoms: The symptoms become apparent only when the combination of both the virus and the bacterium *Streptococcus bombycis* occurs in the susceptible larvae. The characteristic symptom is that the anterior or cephalic end of the insect becomes swollen and almost translucent.

In addition to the clear heads, other external symptoms of gattine are lack of appetite, ejection from the mouth of a clear *ropy* liquid which is slightly more alkaline than the normal secretion, and somewhat accentuated diarrhoea. Further, the digestive tract in the thorax and fore part of the abdomen do not contain any mulberry leaf, but only gastric juice. These areas, therefore, appear limpid yellow and transparent.

Control: Control of this disease depends largely upon the maintenance of sanitary conditions in the rearing rooms. If individual larvae have been affected, they should be immediately picked and destroyed. If heavy infection is noticed,repeated general disinfection during the suspension of all rearing operations is often required to control this disease completely.

(iv) **Fungal diseases**

Muscardine or calcino

The term muscardine originated from the Italian word "moscardino" meaning a musc comfit because the bodies of the insects infected with the fungi are transformed into white mummified specimens resembling in appearance comfits or bonbons. The Italian name "calcino" for muscardine refers to the chalky or lime like appearance of the dead silkworm infected with white, green, yellow or red muscardines.

White muscardine

Causal agent: The causal organism of white muscardine in silkworms is *Beuveria bassiana* (Bal Vuill). This fungus belongs to *fungi imperfecti.* Conidia are round or globular, or, rarely, oval; cylindrical conidia are also found. The conidia appear chalky white collectively but colourless individually. The

conidium at the time of germination swells and gives out one or two germ tubes.

Infection and life cycles: Infection mainly takes place through the skin due to body contamination. *Peros* infection or infection through the tracheal opening may also occur but infrequently. Infection begins soon after the insect's body is contaminated with the conidia of the fungus. Usually infection occurs by a direct penetration of the integument by the infecting germ tube of the fungal conidium. Cylindrical conidia form and spread throughout the body fluid. The fungus continues its development once it is within the body cavity. Blood becomes scanty, blood cells are destroyed and the acidity of the blood reaches neutrality. When the infection has reached an advanced stage, circulation slows down and the consistency of blood becomes pasty. Finally, circulation stops and the insect dies. The conidia germinate in the blood and penetrate into the adipose tissue, muscles, nervous system, silk gland, Malpighian tubules,etc. After the death of the silkworm propagation in various tissues is rapid. The surface of the body becomes covered with mycelium which presents a white mealy appearance after the formation of the conidia. The conidia are readily given off and spread around to cause secondary infection.

The dead insect at this stage also shows a very characteristic production of white crystals on the body surface which have been reported as double oxalate of magnesium and ammonium.

A dead caterpillar is a dangerous source of infection. The larvae are more susceptible to attack by disease during moults. The lfie cycle from spore to spore takes ten days in cloudy weather and about four days in hot weather. The adult moth is seldom infected but once it is it generally succumbs to death more readily than the caterpillar. Transmission from one generation to the next may also occur when the conidia contaminate the external surface of the eggs and infect the larvae that come out from them.

Symptoms: The progress of the disease in the infected larva is very rapid. The larva loses appetite and becomes inactive. Specks of an oozing oily substance may appear on the skin when the disease advances (Fig. 81). The larva may also have diarrhoea and vomit juice. The body becomes limp and loses

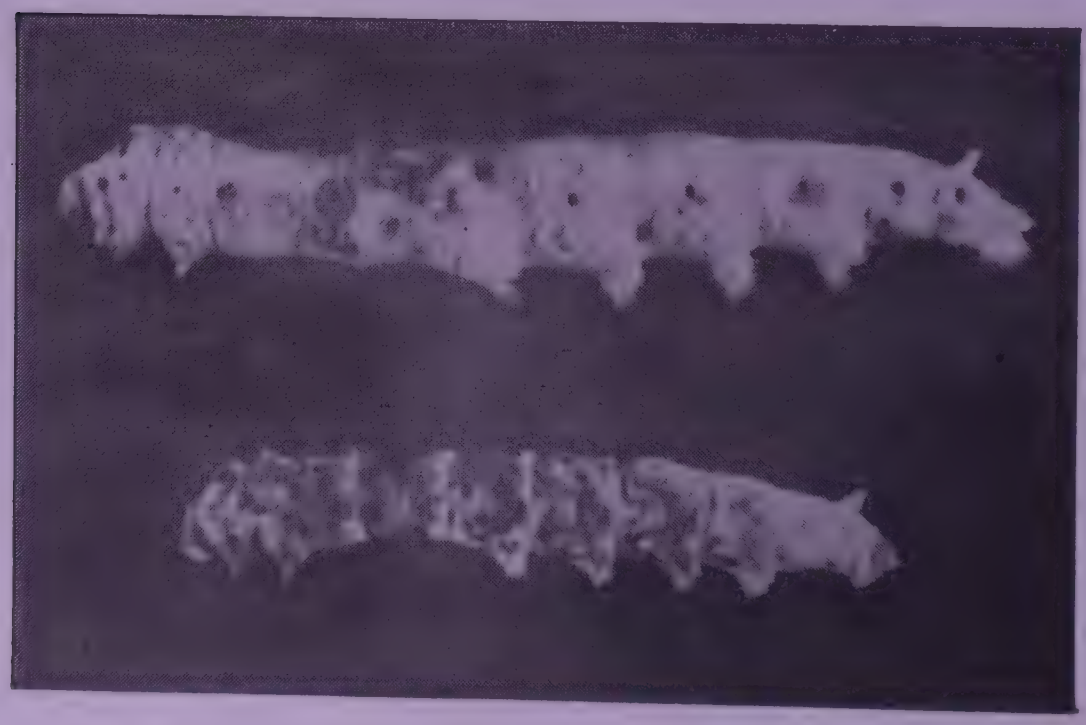
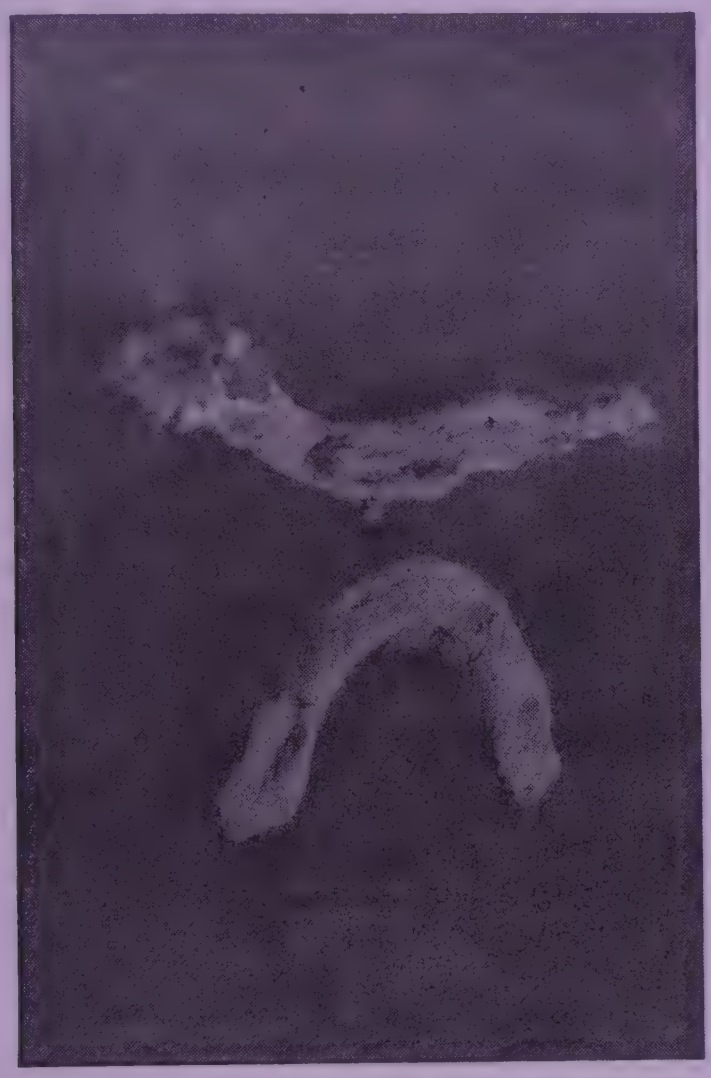


Fig. 81 — White-muscardine affected silkworms showing spots resembling oily specks

its elasticity. The larva ceases to move and generally dies within three to five days of infection. Appearance of a pinkish or reddish tinge has also been reported after death, due to the presence of a red pigmented bacterium called *Serratia marcescens*.

The body generally hardens and becomes stiff. A day or two after death, the body is covered with white mycelia appearing from inter-segmental membranes, spiracles, etc. Numerous conidia are formed on the body which together appear powdery white. The whole body of the dead larva is chalky white and mummified (Fig. 82).



82 — White-muscardine-affected silkworms (Mummified)

If the disease appears just before the caterpillars are about to spin, they may be able to make their cocoons but the moths will not emerge. An infected pupa hardens, becomes covered with white efflorescence and dries to one third of its ordinary weight. Such cocoons sound like dried cocoons when shaken. In the case of the dead moths also, the body hardens and shows the same symptoms.

Prevention and control: There are two types of control measures: (a) control measures taken during the course of rearing; (b) control measures taken in between two rearings or seasons.

(a) **Control measures taken during the course of rearing:**

Infected larvae must be removed and burnt prior to the appearance of the conidia. A convenient method for separating infected larvae from healthy larvae is to use a net. The healthy larvae will crawl to the fresh leaves in the net while the infected ones, which will be inactive, will remain with the litter. Litter should be removed as frequently as possible, and burnt. Muscardine develops rapidly in hot and humid weather. At such times it is better to have good ventilation and low moisture in the rearing room.

Recommendations for application of chemical and gaseous disinfectants without interfering with the vitality and development of the silkworms are available. Burning 100 grammes of sulphur per cubic metre is effective but is also injurious to the insects; this method of control is still practised however. Repeated use of a lower dosage such as 20–30 grammes per cubic metre for a considerable time is preferable. In Japan disinfection of silkworm bodies with formalin is also practised.A 0.7 percent formalin solution is used when temperature is around 27°C or a 1 percent solution at 21°C. The full–grown silkworms are dipped into the solution for 30 seconds to one minute or the solution is sprayed on the silkworm bodies. Spraying young larvae directly is very harmful, so cotton soaked in 0.3–0.5 percent formalin solution is kept in the corners of the rearing box. Another practice is to mix a formalin solution of a definite concentration (0.4–0.8 percent depending on the age of the larvae) with rice bran or burnt chaff in the ratio of 1:10 and spread it over the rearing tray once a day for two days. It is claimed that this is a better method for the larvae from the second to the fifth instar. In the case of newly moulted larvae this is done after the first feeding. This method has to be applied when no leaves are left on the tray. The trays disinfected this way have to be covered with newspapers for about 30 minutes, prior to feeding the larvae. Spraying of high–grade chlorinated lime solution containing 0.1% chlorine till the larvae get wet, is also practised. Half–an–hour after spraying, the trays are covered with nets and a feeding of fresh mulberry leaf given.

Recently ceresan lime has been used. In Japan, ceresan lime, which is a mixture of slaked lime with 5 percent by weight of ceresan, is spread evenly with a sieve on the rearing trays with the silkworms at the rate of five grammes per square foot (0.1 m^2) to control muscardine at the earlier instars. Disinfection is of no use after the penetration of the fungi into the body, so the timing of disinfection is most important. Muscardine of wild insects also infects silkworms. If any wild insects in the garden have been infected with muscardine in large numbers, disinfection of silkworms must be carried out so that the infection is not carried to the silkworms. It is recommended that disinfection of silkworms and rearing beds should be done as soon as one or two silkworms are found tobe infected. Sometimes this may even be too late, because in spite of their healthy appearance, many silkworms in the same tray may have already been affected.

The white muscardine spores are strong in pathogenecity for both the early and late instars. In places where white muscardine occurs often on a large scale, disinfection from a very early age till mounting of worms will have to be undertaken.

(b) **Control measures taken between two rearings or seasons:**

If any infection was observed in the previous rearing disinfection of the rearing rooms and equipment should be carried out immediately after the rearing, instead of waiting for the next rearing time, as this will prevent the conidia spreading. Formalin is most effective since the vapour is penetrating as well as fungicidal. The rearing rooms and all the rearing equipment should be sprayed with a 3–5 percent formalin solution in a closed room. This stronger solution is better since a 1–2 percent solution, which is good enough for routine disinfection, is not strong enough to cope with an active outbreak.

Layings prepared from a rearing where the disease was present should be surface sterilized in a 1–2 percent formalin solution for a few minutes immediately after oviposition is complete.

Green muscardine

What is called green muscardine in Europe is known as black muscardine in Japan.

Causal agent: The green muscardine of Europe is caused by *Metarrhizium anisopliae* (Metch) Sor. It is called green muscardine because of the dark green colour of the spores. The organism belongs to *fungi imperfecti*.

Infection: Infection takes place by penetration of the integument by the germinating hyphae of the spores. After the fungus enters the body cavity it develops in the blood and does not penetrate the tissues until after the death of the silkworm.

Symptoms: Four or five days after infection the larva begins to lose appetite, assumes a yellowish colour and appears sick. In five or six days it becomes extremely feeble and dies, after which the body becomes rigid and brownish yellow. The larva soon becomes covered with a white down consisting of hyphae which shortly becomes the sporophores. A day or two later the rather short and branched sporophores begin to form spores. These soon cover almost the entire body of the silkworm and as they mature, the spores become olive green. The silkworms usually dies in the larval stage. If the larva is infected in the last instar, it may spin a cocoon and die within it.

Control: Measures suggested for the control of white muscardine may be adopted for the control of this fungus as well.

Green muscardine of Japan

This disease is prevalent in Japan and takes a heavy toll on silkworm rearing in autumn. It is comparatively less severe in spring and summer.

Causal agent: The disease is caused by the fungus *Spicaria prasina* (Maubl) Aoki. This conidia are light green single celled, and oval. They germinate in 15–20 hours by a germ tube, at an optimum temperature of 22°C–23°C. The germinating hyphae become mycelia and reach the body fluid of the silkworm and form cylindrical spores.

The spores germinate directly forming a secondary oval spore on their end or divide into two. These spores germinate in the haemolymph of the silkworm and become mycelia which penetrate into various tissues of the silkworm later. The surface of the dead silkworm skin becomes clustered with hyphae which form conidiophores with verticiliated branches, the ends of which bear the conidia.

Infection: Except that the progress of the disease is much slower, the penetration of the germinating hypha of the conidia into the body of the silkworm and their propagation therein are similar to those of the white muscardine fungus.

The younger silkworms are more susceptible to green muscardine than fully grown larvae. The spores of this fungus have a longer incubation period, owing to the prolonged period between the conidial adherence, their germination and the slower formation of cylindrical spores after the entrance of mycelia into the haemolymph. Under natural conditions, this disease mostly affects third instar larvae particularly in the third moulting stage. Because of the prolonged incubation period, infection is considered to take place earlier, especially during the first instar.

Symptoms: Black disease specks of variable shape appear on the skin of the larva and sometimes these coalesce into large specks (Fig. 83). These specks are very clear, appear and a little concave. In

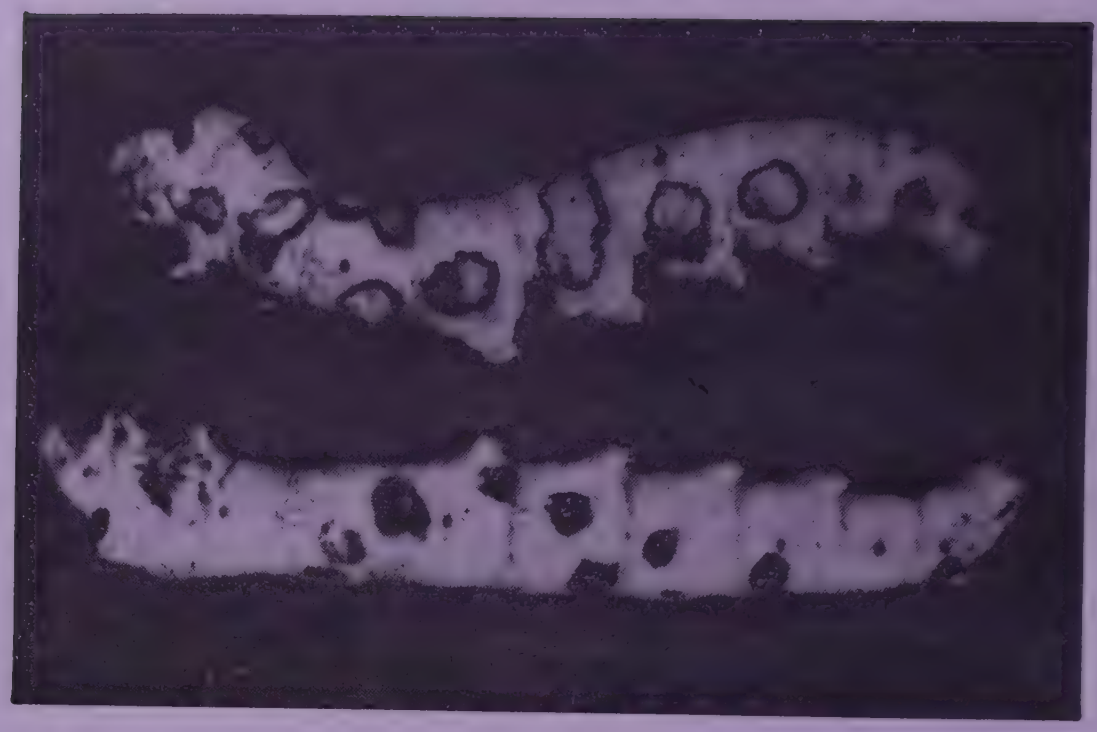


Fig. 83 — Green-muscardine (*Spicaria prasina*) affected silkworms

acute cases, vomiting of fluid and diarrhoea occur before death. The dead worm is soft and elastic at first, but gradually hardens. After death, mycelia emerge from the intersegmental membranes, spiracles, etc., within two to three days and gradually cover the entire body. Ten to fifteen days later, the mycelia bear fresh green conidia which make the body appear green.

Control: As the actual infection is though to take place in the younger stages, early diagnosis and early disinfection of silkworms and rearing beds have an important bearing on its control. When the disease becomes rampant suddenly in the late third instar, disinfection at this late stage may prove to be of no avail. Other control measures are the same as for white muscardine.

Yellow muscardine

The disease is very severe inlate autumn although the attack occurs from spring to autumn.

The causal agent is the fungus *Isaria farinosa.*The conidia are oval, or ball–shaped in some cases. The individual conidium is colourless, but when present in a mass they appear yellow in colour. They germinate by one to two germ tubes. The mycelium produces calcium oxalate crystals in the haemolymph of silkworms. Cylindrical spores produced by the mature mycelium separate and float in the haemolymph and germinate. In dead silkworms the mycelia produce many conidiophores which gather in bunches called synnema, and the top of each conidiophore swells like a club, ramifies and bears the conidia.

Infection: The incubation period is five to seven days in younger larvae, and five to ten days in older larvae. Sometimes curable infection also occurs. Both young and older larvae are affected, but more deaths occur in the fifth instar, the spinning stage and the pupal stage within the cocoon. This disease is more severe in the mulberry pyralid caterpillar than in silkworms.

Symptoms: Many small black specks appear on the skin and sometimes larger specks are seen around the spiracles. Hardening of the corpse and dense formation of mycelia covering the body are the same as in white and green muscardines, except for the formation of conidiophore bundles or synnema. Within ten days after death, the body is densely covered by conidia which appear like yellow powder.

Control measures: The same measures adopted for the other muscardines may be followed.

Other muscardines:

The red and the purplish–red muscardines fungi *Isaria fumosorosea* and *Spicaria rubido–purpurea* respectively, are weakly pathogentic to the silkworms, but are strongly pathogenic to the Uji fly, *Sturmia sericariae*. These pathogens are not important parasites on silkworms and generally the infected silkworms recover.

Aspergillus diseases

Different species of the fungal genera *Aspergillus* and *Sterigmatocysis* cause the aspergillus diseases of which the important ones are the following:

(a) *Aspergillus flavus* Link

(b) *Aspergillus oryzae* Wehmer

(c) *Aspergillus ochraceus* Wilm

(d) *Sterigmatocystis fulva* (Mont.) Sacc.

(e) *Sterigmatocystis japonica* Aoki.

(f) *Sterigmatocystis* sp

Infection and symptoms: The above fungi attack younger silkworms but are not pathogenic enough to affect grown larvae. Affected young larvae exhibit body tension and lustre, and finally die. No noticeable disease specks are produced. Soon after death mycelia propagate over the corpse and form conidia which present the specific colour of the species. Generally, the corpse of younger larvae is covered with mycelia but it does not decompose. When a grown–up larva is affected, the germinating tubes penetrate into the body, and grow slowly. Hence a grown larva is often partially decayed. In those species of *Aspergillus* and *Sterigmatocystis* where no cylindrical spores are formed in the haemolymph, propagation of the pathogens is limited to the area of penetration and the affected silkworms are able to recover from the disease after the moult. Even if the silkworm dies, hardening of the corpse takes place only in the area where the fungi have penetrated.

Control: The timing of disinfection is most important and disinfection against the fungi of *Aspergillus* diseases should be carried out in the early larval stages as infecton and penetration takes place mainly in early instars of the larva. In other respects the control measures are the same as for the white muscardine. Since formalin is ineffective against species of *Aspergillus,* other chemicals like pentachlorophenol may be used for control purposes.

SILKWORM PESTS

Among the insects that attack silkworms, the most important ones are the parasites *Tricholyga bombycis* Beck., *Tricholyga sorbillans* Wiedman, and *Sturmia sericariae* Cornelia (*Cross ocosmia sericariae*) which are commonly known as "Usi" or "Uji" flies.

The dermestid beetles, with some exceptions, damage mostly in the stifled and stored cocoons for the animal matter inside. They are quite common, but are not parasites *in se*. Other insects such as ants, wasps, earwigs, crickets and preying mantis also attack silkworms but they are generally of minor importance as pests. Pests and parasites from groups other than insects are a mite *Pediculoides ventricosus* Newport, a spider *Theridion tepidariorum* and a nematode *Hexamermis microamphidis*. Rats and squirrels also can do considerable damage to silkworm rearing but these are general domestic pests.

Uzi fly *(Tricholyga bombycis)*

Tricholyga bombycis , a dipteran fly of the family Taohinidae, commonly known as Uzi or Uji fly, is a serious pest of silkworm larvae and pupae. It is prevalent in Burma, China, Thailand and in some states of India. This fly is principally a parasite on mulberry silkworms but it has been known to attack *tasar* silkworms also; it is the Indian counterpart of the Japanese tachinid fly, *Sturmia sericariae* (*Crossoosmia sericariae)*. This fly can cause considerable damage to silkworm rearing and as a result the sericulture industry freqently suffers in the cocoon crop production.

Life cycle, habit and nature of damage: *T. bombycis* is a large fly with prominent black and grey stripes and dark ebony in colour. The female fly when it gets to the silkworm larvae of later instars lays white, glossy, small, oval eggs on the body or at the intersegments. In the first and second instars silkworms are seldom host to this fly pest as they are too small and are not sufficiently attractive to the fly pest and the young stages of silkworms are practically free of infestation. Ordinarily the fly pest prefers the later instars (third, fourth and fifth) to the earlier ones of the silkworm for oviposition.

Each female fly lays about 300 eggs. The egg hatches within one to three days of oviposition and the young maggot bores its way into the bodyof the silkworm larvae. A black spot or scar appears on the body of the silkworm at the point of entry after penetration of the maggot (Fig. 84). The maggot lives on the tissues of the silkworm especially the fat bodies, for about a week and gets its air supply from the

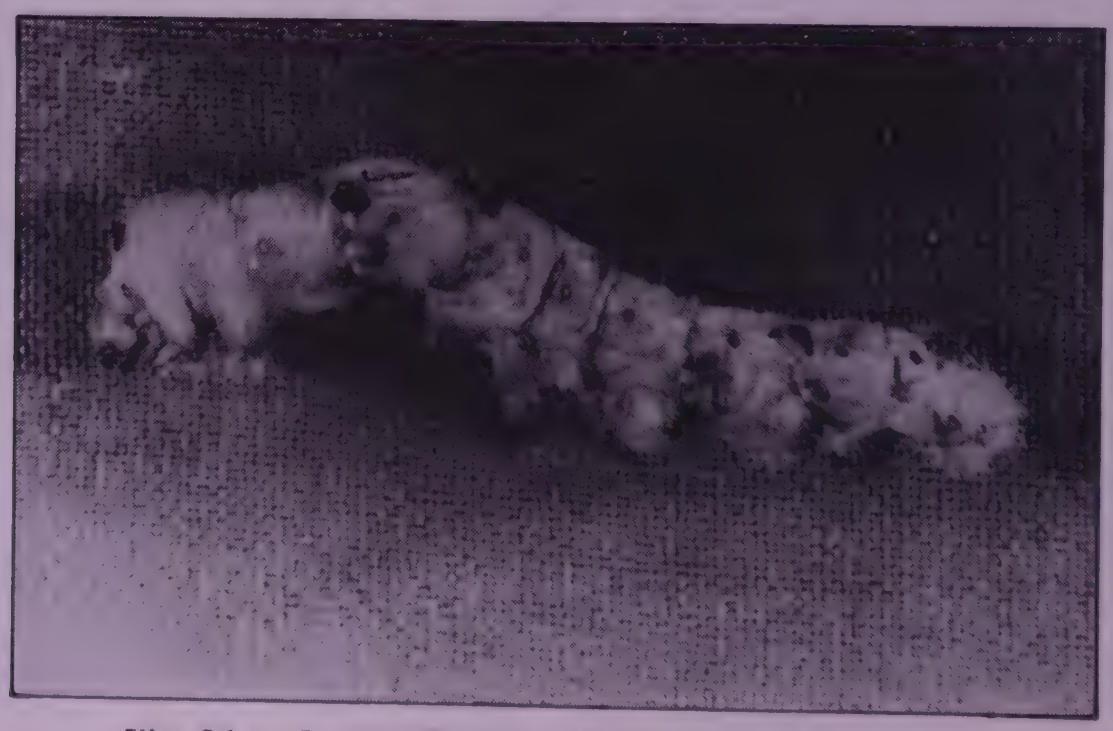


Fig. 84 — Larva affected with *Tricholyga bombycis*

aperture through which it entered. The maggot lives in the body cavity of the silkworm for about a week and having finished feeding, the fully grown maggot wriggles its way out killing its host (Figure 85a). If the infestation takes place in the late fifth instar of the silkworm, the larva maybe able to spin its cocoon, but the cocoons cannot be used as seed cocoons and are also unreelable since the fully grown maggot makes its way out of the silkworm pupa and cocoon, for pupation in the soil, by killing its host and cutting the cocoon layer. In any case the damage is serious because either the silkworm larva itself is killed or the spun cocoons are rendered useless for reeling or for seed purposes.

Fig. 85 — Maggots and pupae of *Tricholgya bombycis*

The maggot selects soft soil and pupates within a day (Fig. 85(b)). The adult fly (Fig. 86) emerges in about 10–14 days and starts a fresh life cycle. The entire life cycle takes about 17–23 days under Indian climatic conditions.

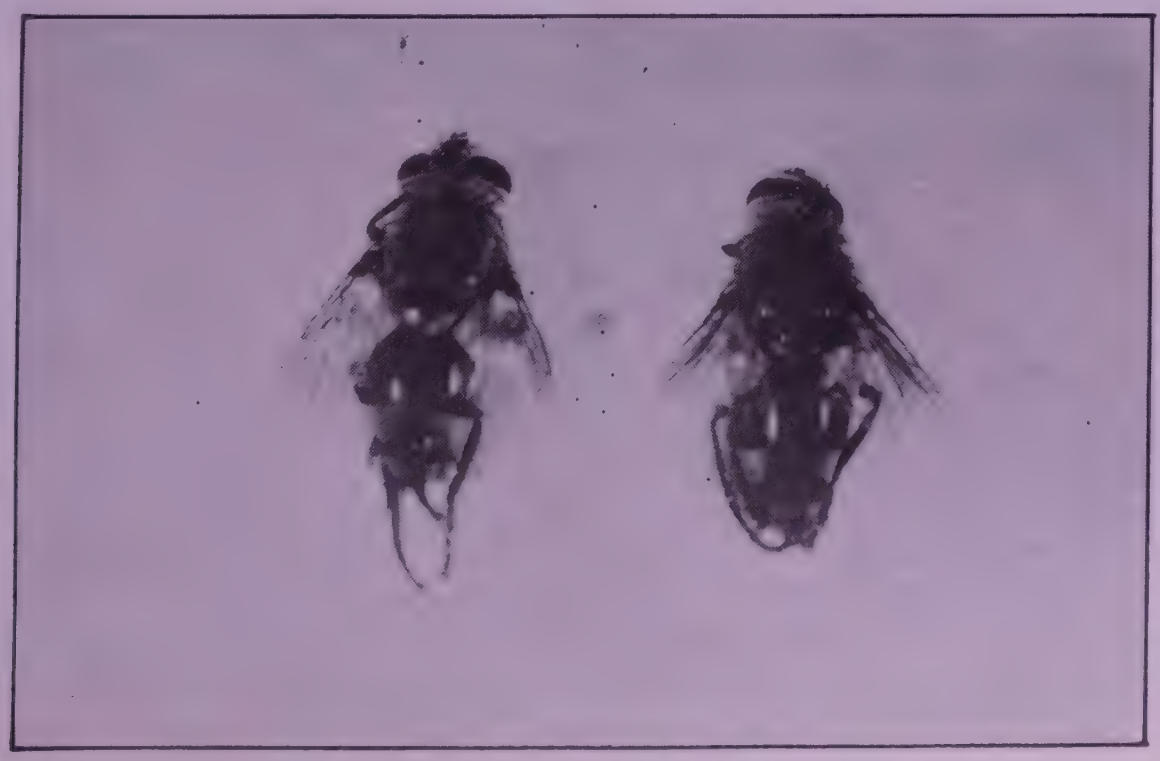


Fig. 86 — Adults of *Tricholyga bombycis*

The larvae affected in the third and fourth instar die invariably before they reach the spinning stage. If they are affected in the early fifth instar, most of them die prior to spinning, whereas others die after spinning their cocoons normally. In such cases, since the worms die inside their cocoons and subsequently rot, the cocoons are stai and unfit for reeling. This fly infestation has a significant negative effect on the length, width and also the shell weight of the cocoon.

Prevention and control: The most effective method of control is to prevent the entry of the fly into the rearing rooms by providing suitable wire mesh (fly-proof nets) for doors, windows and ventilators, wherever rearing is done in separate rearing houses or rooms. Pest-trapping rooms may also be provided at the entrance, but this may not be financially feasible for poor rearers. The maggot infected larvae and cocoons must be destroyed by burning or by treating with chloropicrin. All crevices on the floor must be closed up to prevent the maggots from creeping under the floor to pupate.

Uji fly *(Tricholyga sorbillans)*

The Uji fly is found in China, Korea and south-east Asian countries. It produces seven to eight generations a year in tropical zones and is quite hazardous. It is hardly considered a pest of silkworm in Japan and yields only five to six generations a year.

The adult looks like a house fly but is usually bigger (Fig. 87). The body is greyish yellow with four stripes along the length of the thorax. The eggs are light yellow.

Fig. 87 — *Tricholyga sorbillans*
Left Female Fly
Right Male Fly

Life cycle, habit, nature of damage and control measures are generally similar to that of *Tricholyga bombycis.*

Japanese Uji *(Kyoso fly)*

The entomological name of the Japanese Uji fly is *Sturmia sericariae or Crossocosmia sericariae* and is also of the family Tachinidae. Unlike the Indian Uzi fly, *T. Bombycis,* which lays its eggs directly on the silkworm larva, the Japanese Uji fly lays its eggs on the lower side of the mulberry leaves along the leaf vein.

The body of the adult is greyish black and the ventral side is rather pale. Large reddish brown half-circular dots are prominent on bothsides of the abdomen of the male fly. The male fly is larger than the female fly. The maggot is pale yellow and cylindrical gradually tapering toward the anterior end. The egg is oval with a sharp end, black and has net-like markings on the surface.

Life cycle, habit and nature of damage: The mated female flies to the mulberry field, perches on a leaf, quickly moves behind it and lays one or two eggs along the leaf vein. Soon after oviposition, the fly moves onto the surface of the leaf, goes to another nearby leaf and repeats the same behaviour of oviposition. It lays eggs on chestnut, cherry and other trees, but the mulberry is preferred for oviposition. A female fly lays about 3000 to 5000 eggs in a month. The adult feeds on the secretions of the aphids and scale insects which parasitize pine trees in particular.

The eggs swallowed by the silkworms togther with mulberry leaf hatch out in the gut through the action of the silkworm's digestive juices. The young maggots bore their way through the wall of the digestive canal and penetrates into the ganglia (mostly the fourth to the seventh ganglia) of the nervous system and remain there for one to two weeks. Then they foresake the nerve ganglia, attach themselves to the spiracle of the host by their tail ends, and breathe through the spiracle while eating the body tissues of the host with their mouths. The tissue of the silkworm around the spiracle dies and becomes black.

Younger (first and second) instars of the silkworms are unable to swallow the parasite's egg stuck to the leaf, or the egg gets crushed in the mouth. In the majority of cases the fourth and fifth instar silkworms are the host. Generally one or two maggots parasitize a single silkworm but sometimes a few maggots may be found. When the silkworm is severely parasitized, it does not spin or pupate, but dies. If it is parasitized by only one or two maggots it may spin its cocoon. The maggots come out of the silkworm cocoons, as in the case of *T. bombycis,* and causing a similar type of damage to pupate in the soil. But unlike the pupa of *T. bombycis,* the pupa of *S. sericariae* spends the winter in the soil and becomes adult the following spring.

Prevention and control: Prior to feeding, soaking mulberry leaves for five minutes in water heated to 50°C, or fumigation of leaves with naphthalene (5 g per 1000 cm^3) or disinfection of leaves with steam heat at 50°C for ten minutes is very helpful in killing the eggs of this parasite. Subjecting the pest-infected pupae to ultra high frequency vibration has been found effective in obtaining healthy silk moths for egg laying.

If possible the ground where the raw cocoons are gathered must be cement-paved so that the maggots will not be able to enter the soil for pupation and maggots and pupae can be easily collected and burnt.

Dermestid beetles

This group of insects belongs to the order Coleoptera, family Dermestidae. This family contains many genera and a number of very destructive species. Most of the damage is done by the larvae when cocoons are stifled and stored for a long time; holes are bored and the pupae in them eaten. In addition to this, they damage animal and plant products including leather, furs, dried fish, carpet, woollen and silk materials.

The following are some of the dermestid beetles that are important from a sericulture point of view:-

(1) *Dermestes cadverinus* Fabricius

(2) *Dermestes valpinus* Fab.

(3) *Dermestes vorax* Motschulsky

(4) *Dermestes frishchi*

(5) *Dermestes tesselatocollis*

(6) *Dermestes coarctatus*

(7) *Trogoderma versicolor*

(8) *Anthrenus verbasi* L.

(9) Anthrenus pipinellae Fab.

(10) *Attagenus piceus* (Oliver)

(11) *Attagenus japonious* Reitter

Morphology of Dermestes Cadverinus: The adult is oval, elongated, dark brown with club-shaped antennae, and is about 1 cm in length. The larvae have their upper surface covered with hairs of various lengths. The larvae are reddish-brown and spindle-shaped (Fig. 88). They moult five to seven times and attain a length of about 15 cms. The elongated oval eggs are 2 mm in length, and are milky white in colour.

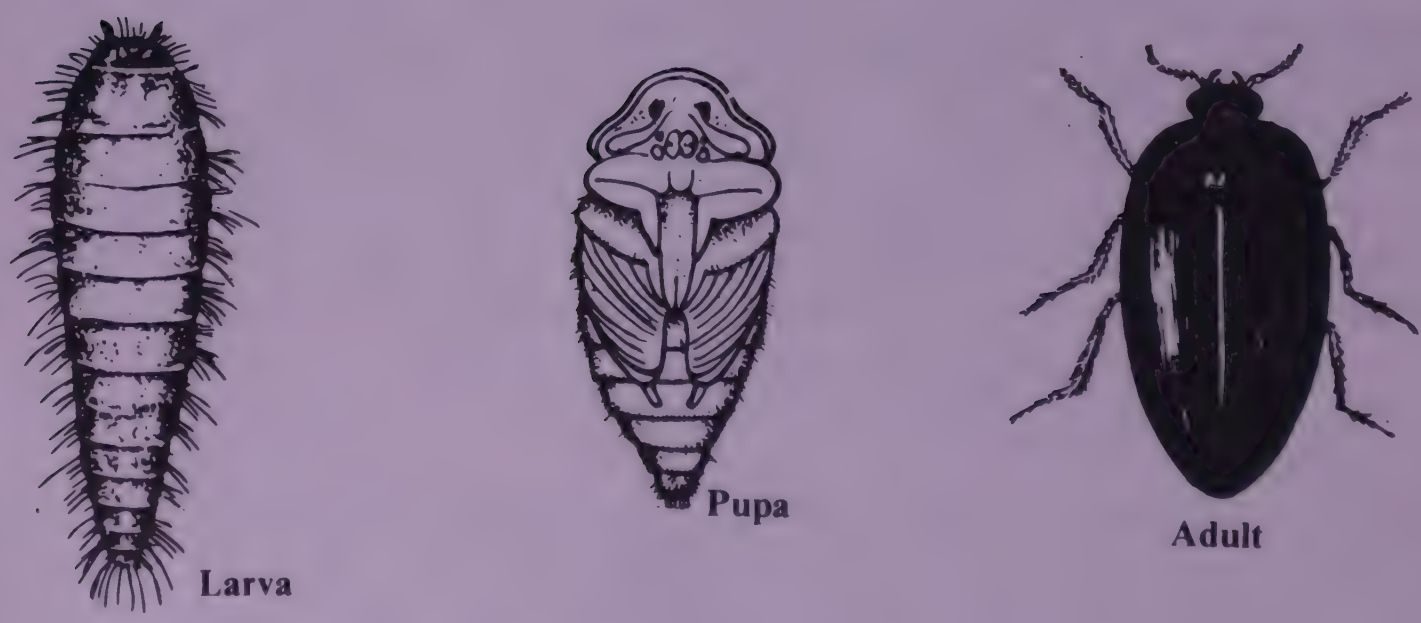


Fig. 88 — *Dermestes Cadverinus*
Larva, pupa and adult

Life cycle, habit and nature of damage: Generally the insect passes the winter in the adult stage, begins mating and starts laying eggs in May. The adult lives on animal matter for one year after oviposition. The female beetle moves around in dark areas of the cocoon storage and deposits its eggs in the crevices of dried organic matter, slits in wood, etc. The egg hatches in a week and the young larvae starts feeding on dried animal matter. The insect prefers to live in darker places. It moults five to six times in one or two months and becomes a pupa. The adult, after emergence, mates and lays eggs which develop to become the adults of the second generation. Although the insect generally passes the winter in the adult stage, since the time of metamorphosis is not fixed, both the larval stage and the pupal stage may be encountered in winter.

The larvae and adults are attracted by the smell of stiffed cocoons and the dried pupae inside. The bore into the cocoons and eat the dried pupae and sometimes the eggs and the damaged cocoons become unfit for reeling. Rarely, the young larvae attack living silkworms.

Other Dermestes species

Dermestes vorax produces only one generation a year where as*Dermestes valpinus* yields three.The larvae of these two species are quite similar in appearance. Both the larvae as well as the adults prefer dark places and fee don dry animal matter. The result *D. valpinus* is black and the adult *D. vorax* has a red strips on its back. *Dermestes frishchi* dwells in humid places and develops better at high temperature; it eats away pupae and moths.

Anthrenus verbasi: Eggs are 0.5 mm long, oval and milky white. The larvae are grey–brown, swollen at the tail and have an elongated tumbler–shaped body. The full–grown larvae are about 3–4 mm long. Adult beetles are 2–3 mm in length, convex, slightly elongated and roundish with yellow–white scales on a black background.

The female beetle lays eggs (20–100 eggs) on some living matter, or dust or in between wooden boards. The eggs hatch in about 25 days or so.The larvae prefer dark places, feed on dry animal matter,and moult six to seven times by the end of the summer. They pass the winter in the larval stage and become pupae by the next April. In May, a few days after developing wings, they come out, mate and being oviposition. The adult at this stage prefers darker places. During the later part of the oviposition period, they change their preference for darker places and fly to the daylight. By this time most of them will have completed oviposition. The adults are often found on flowers in the nearby garden during May and July; they live for about a month and thus they yield only one generation a year.

The larvae damage cocoons — sometimes freshly spun cocoons — by boring holes in them, they damage raw silk and sometimes also feed on dry silkworm eggs. The adults' presence on plant material and their preference of daylight during their later part of life cycle are the characteristics which distinguish them from members of the genus *Dermestes.*

Other *Anthrenus* species: There are other species in this genus but they are more or less similar in that they are all small, prefer animal matter for feeding only in the larval stage and pass the winter as larvae. Anthrenus pipinellae resembles *A. verbasi* but produces two generations a year and the adult has white stripes on its back.

Other dermestids: The dermestid *Trogoderma versicolor* preys on dry moths, dried cocoons, perished and dried up eggs.

Attagenus japonicus has generally one generation a year and the adult isblack and spindle–shaped.The larva is reddish and has an elongated triangular shape. The larvae of *Attagenus piceus* damage cocoon floss, cocoon fibres and intact raw silk. The sericin in intact silk seems to attract the larvae.

Control measures forall *dermestids:* To avoid damage by dermestids, the rearing house and the cocoon store rooms must be cleaned frequently. Storing of rejected cocoons and perished eggs for long periods is to be avoided. Before and after emergence of moths the egg production premises must be cleaned.

Fumigation of dried cocoon storage rooms can also be done at times with methyl bromide,0.5 kg per 283 m^3, for a day or with chloropicrin 0.5 kg per 283 m^3 for three days taking the necessary precautions. The rooms must be properly shut off and all the opening closed up with paper before fumigation. Spraying with BHC can also be done if the cocoon storage room is away from the rearing house. Precautions must be taken to prevent the silkworms from coming into direct contact with the insecticide or fumigant.

The mite, *Pediculoides ventricosus* (Newport) Targioni–Tozzetti

This is not an insect pest but belongs to a group of mites, order Acarina and class Arachnid

Habit: This mite is sometimes encountered at the time of re–thatching of the roof of the silkworms rearing house or is brought into the rearing house with building materials such as straw, wood or bamboo. The female mite attacks silkworms larvae, pupae and adults causing death. Also other insects such as the rice borer, powder post beetle, (*Lyctus brunneus* Steph.), and *Sitotroga cerealella* (Oliver), which is a pest of wheat and rice, are parasitized by this mite.

Life cycle: The males and females are different in shape. The fully grown female has a swollen, round abdomen 30 times the normal ordinary size (Fig. 89). It passes the winter as a mature female.

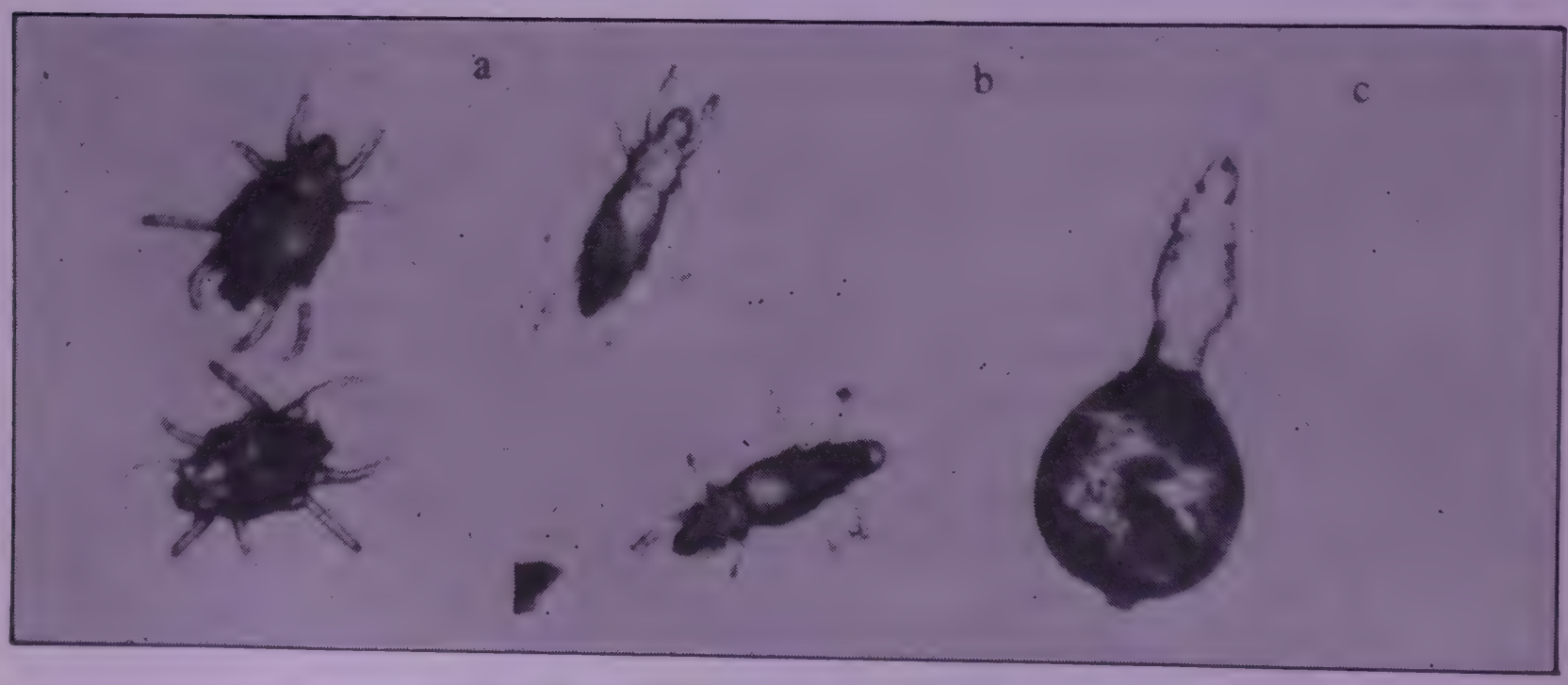


Fig. 89 — *Pediculoides Ventricosus*
(a) Adult male
(b) Female
(c) Mature female

Between May and September, seven generations are produced.

The males die a day or so after mating and the female goes out in search of its host, e.g. the silkworm, attaches itself to the body of the silkworm and in a week develops a swollen abdomen containing eggs. Young larvae and pupae of silkworm are its preferred hosts.

Nature of damage: The body surface of a silkworm stuck with this mite, develops a few black specks. The infested silkworms loses appetite, becomes inactive and has difficulty in excreting. It takes time to pass the excreta and frequently the excreta are attached bead-like to the anus. If severely parasitized, the silkworm vomits yellowish-green fluid and excretes black fluid from the anus. Irregular and decreased pulsation of the dorsal vessel is also observed. The mite takes nutrition from the silkworm and gives out a toxic substance which kills the silkworm. If the attack is mild, the silkworm takes many hours to die; if it is acute, it dies in a few hours and starts putrifying. Young silkworms do not putrify rapidly.

Prevention and control: As mentioned above, this mite is brought into the rearing house with building materials such as straw, bamboo, etc., therefore they must be handled carefuly as this mite also parasitizes other insects such as *Sitotroga cerealella* which is a pest of rice and wheat; precautions must be taken not to store wheat or rice straw near the silkworm rearing house. Building and re-thatching materials must be treated with acaricide or insecticide or fumigated before use.

Ants (Order: Hymonaptera. Family: Formicidae)

This insect pest attacks silkworms in the rearing trays and this can be prevented by placing the legs of the rearing stands in ant wells. When the ants attack is at the time of spinning, a little kerosine can be poured on the floor around the legs of the chandrikes or bamboo mountages, two of which are usually kept slanting in the form of inverted "V".

Nematode

Nematodes belong the phylum. Nemathelminthes and class Nematoda. The nematode *Hexamermis microamphidis* is mostly found in silkworms of late-autumn rearing. This organism attacks the young-stage larvae and penetrates into their bodies. The head of this affected silkworm becomes transparent and the body silky white.

Lizards

These commonly frequent the rearing houses and often pick up the young-age worms and eat them, thus causing considerable damage.

Rats and Squirrels

These mammalian predators eat the silkworms avoiding only the silk glands and the pupa after biting open the cocoons. Their entry into the rearing house can be prevented by providing suitable wire mesh (fly-proof nets) for doors, windows and ventilators. Traps and poisonous baits can also be used.

Birds

Birds such as crows and sparrows pick up the silkworms when the mountages are kept out-of-doors at the time of spinning. Damage by these predators can be avoided by keeping the mountages indoors at the time of spinning.

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FAO AGRICULTURAL SERVICES BULLETIN

FOOD AND AGRICULTURE ORGANIZATION
OF THE UNITED NATIONS ROME

Sericulture Manual

3 — Silk Reeling

sericulture manual 3 — silk reeling

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FOREWORD

In recent years, the governments of many developing countries have given added attention to the production of natural silk. Indeed, sericulture offers many advantages, such as:

a) helping to keep the rural population employed and to prevent migration to the towns,
b) securing remunerative employment,
c) earning much needed foreign currency,
d) requiring no large investments,
e) providing raw material for cottage and even large-scale textile industries.

One of the main obstacles to the development of silk production and the promotion of silk industries is the shortage of up-to-date literature. In order to help fill this gap, the Agricultural Services Division is preparing a **Manual on Sericulture** that will consist of three volumes:

Volume 1 — Mulberry Cultivation
Volume 2 — Silkworm Rearing
Volume 3 — Silk Reeling.

The present volume which deals with silk reeling is the first to be published; the other two will follow at the beginning and at the end of 1973, respectively. Readers are invited to submit suggestions and comments that would be useful in editing Volumes 1 and 2 to:

Chief, Food and Agricultural Industires Service
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Chapter 1
INTRODUCTION

Silkworms are reared for the sole purpose of obtaining cocoons which form the raw material for producing raw silk. It was discovered several milleniums ago that the cocoons of the silkworm could be softened in hot water and the continuous silk filaments could be drawn therefrom to produce well united and strong threads of uniform thickness for the manufacture of beautiful and durable fabrics.

Rearing of silkworms for the production of cocoons constitutes sericulutre, while reeling is concerned with unwinding of the silk filaments of the cocoons through suitable techniques to form a composite thread fit for weaving. It is in essence an industrial sequel to silkworm rearing and thus the two are interdependent on each other's economic stability and prosperity.

Although the bulk of silk used in trade is produced by the mulberry silkworm *(Bombyx mori)* there are many other kinds of silkworms such as **tasar** *(Anthrea mylitta)* , **muga** *(Anthrea assama)* and **eri** *(Philosamia ricini)*, which are of commercial importance. Tasar is wild and not systematicaly cultural like the mulberry silkworm. Next in importance is muga silk, which is exclusively produced in Assam, India, Eri silkworm, which is found in Asia and America feeds on castor leaves and is reared indoors. Attempts made to culture certain special varieties of spiders for obtaining silk for manufacture of unique types of textiles proved futile, as the silk was found unsuitable for textile manufacture. The wild silk industry is only of local importance and the total output of wild silk forms no more than one to two per cent of the total world output of silk. Wild silks are generally coarser and less uniform in thickness. Because of the uniqueness of wild silks and their peculiar appearance, they have a novelty value and a ready market.

Raw Silk or Grege

The term raw silk (Grege) in industry or commerce is commonly understood to denote mulberry raw silk. It is the compact untwisted and undegummed silk thread that is formed by combining the required number of silk filaments drawn from as many separate cocoons by a special technique called reeling. This is a series of skilled operations dealing with a raw material which is composed of an extremely fine, continuous silk filament of great length, unlike other natural textile fibres. Reeling demands constant attention and care on the part of the reeler, since during the process of reeling the cocoon filaments break continually and the reeler must promptly attach a fresh filament which is always kept ready in reserve. Lack of attention results in the abrupt occurrence of thin lengths in the reeled thread. A skilled reeler can rectify a break of filament by attaching a fresh filament quickly even before half a metre has been wound on the reel.

The art of reeling is generally believed to have originated in China nearly three thousand years ago, and it is said that for a long time it was kept a carefully guarded secret. It remained a virtual monopoly of China for a long time.

Filature

The building in which cocoons are reeled for the production of raw silk is called a filature. The modern filature is an elaborately organised reeling factory, using electric power and employing advanced technology with sophisticated automatic machines, to ensure production of raw silk of desired qualities according to a pre-determined plan and at economic cost. Filatures of this concept are mostly to be found in countries where the bulk of the cocoons are of superior quality; and where labour is both scarce and costly. In this system of automatic reeling, the productivity of the machine and the quality of reeled silk depend primarily on uniformity in the quality of the cocoons. In countries where the bulk of cocoons produced is not good enough for highly mechanised and automatic reeling and where reeling can be practised as a labour intensive indsutry, filatures do not make use of labour-saving automatic machines. Instead highly efficient multi-end reeling machines with auxiliary equipment are installed and rational techniques of production are adopted. Productivity and quality of raw silk in such filatures, though mainly dependent on the quality of cocoons, are also dependent on the skill of the reeler.

Reeling as a Cottage Industry

In addition to these types of large and small filatures, there are also small reeling establishments organized as a home or cottage industry, usually in the remote rural areas of cocoon production. These cottage establishments, whose financial resources are limited,use cheap and simple reeling appliances obtained locally. The appliances are either foot–powered or hand–driven, with simple methods of raw silk production. These establishments are highly individualistic in character and are to be found in almost all the sericultural countries, but predominantly in sericultural areas where multivoltine races of silkworms are reared throughout the year and fresh cocoon crops are available at frequent intervals. Thus the reeling Industry of the Cottage type has neither set patterns of organization nor standardised equipment and production techniques. It has fashioned itself to suit firstly the quality of cocoons available in the locality and secondly to the several compelling factors of industrial and economic conditions prevailing in the country. But whatever be the pattern of organization, the aim of reeling in the cottage sector is always to obtain the maximum yield of raw silk from cocoons at the minimum cost of material and labour,and to produce such qualities of raw silk as would satisfy all classes of silk weavers and other pure silk utilising industries. To what extent these objectives are attained depends upon several variable factors but primarily on three essentials, namely the quality of cocoons used for reeling, technology of reeling and the skill of workers engaged in the several operations of reeling.

Chapter 2

COCOON QUALITY

(i) Importance of Quality of Cocoons

The cocoon is the raw material used for reeling raw silk. It is, in fact, a protective shell made up of a continuous and long proteinaceous silk filament spun by the mature silkworm prior to pupation for self protection from adverse climatic factors and natural enemies. Economics of reeling and the quality of the reeled product depend largely on the quality of cocoons used for reeling, and therefore, it is of vital importance that the cocoon quality should be good.

A good quality cocoon need not necessarily be large in size but it should be firm and compact in build, uniform in shape and size as far as possible, rich in silk content, contain less of floss but more of easily reelable silk. Lastly, cocoons in a given lot should be of one variety.

Temperature & Humidity Conditions during Cocoon Spinning

The aim of the silkworm rearers should be to produce good quality cocoons, so that raw silk of superior qualities may be produced at economic cost. The quality of the cocoon, especially its build and reelability, is determined not only by the silkworm variety but also to a large extent by the care taken at the time of cocoon spinning. The mature worms are very sensitive to physical disturbances and to factors such as temperature, humidity, light, etc. at the time of spinning. It is, therefore, necessary to provide the optimum conditions to enable the silkworms to spin good quality cocoons. Thus cocoon spinning is a critical stage in sericulture for both the silkworm rearer and the raw silk reeler, and it is for this reason that experienced silk reelers maintain constant touch with the sericulturists and keep a close watch on the rearing performance of the silkworms especially the behaviour of the silkworms at the cocoon–spinning stage.

For production of good quality cocoons it is also necessary that all the worms should spin uniformly at the same time and that the worms should be mounted at the proper time of maturity.

Density of Mounting

The ripe worm ordinarily requires a space equal in area to the square of the length of its body, for spinning its cocoon so that too much silk may not be wasted for building the preliminary web. This would mean that in an area of one square metre about 800–900 ripe worms can be mounted. Worms should not be mounted too densely as it would increase the incidence of double cocoons as well as stained cocoons due to the excretions and natural evaporation of moisture from the body of the larvae besides increasing the humidity of the mounting room which is detrimental to the spinning of good quality cocoons.

Care after Mounting

Silkworms generally defecate prior to the commencement of spinning and so in order to prevent staining of cocoons, it is advisible to keep the mountages in an inclined position so that the excreta may drop to the ground and not on the worms or cocoons already spun on the mountages.

Temperature

The quality of the cocoon it spins will be good when the environmental temperature during the spinning period is kept between 22^{0}C and 23^{0}C. Higher temperature increases the mortality of worms on the mountage. This temperature is maintained till the spinning is completed and then the temperature is raised to 24^{0}C till the cocoons are harvested. Multivoltine races reared in tropical climates, however, are known to tolerate slightly higher temperatures.

Ventilation

Humidity in the mountage room is apt to increase for two important reasons; firstly the mounted larva loses as much as 40 per cent of its body weight due to natural evaporation of its body moisture, and secondly the larva has a tendency to discharge liquid excreta prior to commencement of spinning. It has been estimated by experiments that nearly 40 ml of urine is excreted by 100 worms. If the humidity in the mounting room increases beyond the optimum level, the quality of cocoons will be affected. To avoid this, it is necessary to provide adequate ventilation to the room by keeping the doors and windows open. These should be closed only when it is raining or when the outside humidity is higher than that required in the room. In addition to providing sufficient ventilation, in certain seasons, straw mats are also spread below the mountages for absorbing the liquid excreta and when the mats get soaked, they are removed and replaced by dry ones.

Humidity

For undisturbed and uniform spinning of cocoons the humidity should range between 60–70 per cent. A higher humidity may result in a reduction in the quality of cocoons. Sudden rise in temperature or humidity causes abrupt thinning and thickening of the silk filament. Abruptly thickened and thin portions of the silk filament in the cocoon lead to poor reelability.

Light

The mountage room should be provided with even and moderate lighting. Too bright and improperly placed light produces dark shadows in the grooves of the mountage and causes the worms to move towards the shaded areas and crowd there. This increases the formation of double cocoons and the occurrence of soiled and stained cocoons.

Silk Gland

When a ripe silkworm is dissected a pair of large glands will be seen lying on either side of the intestines. The ducts from these glands unite in the spinneret below the mouth of the silkworm and the entire structure is called silk gland. Each of the pair is very long and several times the body length of the larva and lies in a series of folds. The whole gland is made up of about 1000 cells (Fig. 1) formed at the embryonic stage itself, the cells only enlarging with the growth of the larvae. The silk gland consists of three distinctive and functional parts — the posterior, middle and the anterior. The posterior ends of the glands are closed while the fore-ends converge to join together into a common excretory duct opening into the spinneret near the mouth.

The posterior part secretes the silk substance known as fibroin, while the middle part serves as a reservoir for receiving the fibroin from the posterior silk gland. It also secretes round the fibroin a natural gummy substance called sericin. The anterior part which is actually a silk duct or excretary canal moulds the sericin coated fibroin and conveys it to the spinneret. Here a pair of Fillippi's glands which are situated on either side of the common duct elaborate certain secretions which help unite the moulded silk material from the two excretary canals and prevent the freshly moulded silk from hardening. The silk substance hardens into silk filament or bave only on coming into contact with air. It is made up of two independent fibroins called Brins from the two glands and is covered completely with sericin. It is the continuous long silk bave that makes up the cocoon shell.

The composition of the cocoon shell is given in the table below :

Fibroin	72.0–81.0%
Sericin	19.0–28.0%
Fat & wax	0.5– 1.0%
Colouring matter & ash	1.0– 1.4%

Fibroin forms about 76 per cent of the whole weight of the composite bave,and sericin about 22 per cent, the rest being wax and other substances.

Spinning of the Cocoon

Soon after the ripe larva is left on the mountage it anchors itself to the mountage by oozing a very tiny droplet of the silk fluid which immediately hardens on the surface of the mountage and sticks to it. Then by continuous movements of the head, silk is excreted in minute quantities which goes on hardening to form long continuous filament or bave. The bave so formed is used for the construction or spinning of the whole cocoon.

The silkworm at first proceeds to lay the foundation for the cocoon structure by casting a loose tracery of silk from one point of anchorage to another drawn in long straight filaments of 2.5–3.5 cm or even 5 cm. This foundation layer is the preliminary web, made up of a continuous filament but the deposition of the filament is not orderly but tangled. This web provides the necessary foothold to the larva for leisurely and methodical spinning of a densely woven strong shell, which generally takes from three to four days for completion. This foundation layer which covers the compact shell is called floss or blaze.

After the preliminary web has been built, the larva settles down to weave the compact shell depositing the bave in a more or less regular pattern. Due to the peculiar movements of the head of the larva, the bave is deposited in a series of short waves or in eyelets like the figure '8'. The former pattern is usually found in the outer layer of the shell and the latter in the inner layers, (Fig. 2). When 20–30 such patterns are made in one area,the worm moves its head away to another zone to repeat the operation. Each group of such deposition of bave is called a bundle or group which commonly occupies an area of 4 to 5 mm^2. These groups, though formed in different areas of the shell, have a continuous filament running through them. A large number of such groups make one layer and five to six layers make the compact silk shell.

After the completion of the compact shell, the now shrunken larva wraps itself with a gossamer layer and finally it detaches itself from the shell to transform into an inert pupa or a chrysalis. This last layer is only a body sheath of the worm and does not form a part of the main compact shell, although the filament forming it is an extension of the filament of the main shell. This body sheath is known as the pelade layer. The outer floss and the innermost pelade together made the waste known as frisons. Thus the whole cocoon is made up of one continuous filament or bave. Breakages in the bave occur only when the larva is violently disturbed during cocoon spinning. A cocoon has three distinctive layers viz,the outer flows or blaze, the middle compact shell which constitutes the reeled silk and the innermost pelade layer. The outer floss and innermost pelade which do not yield any reeled silk form waste.

Recovery of Silk in Reeling

In terms of percentage of recovery of silk in reeling,it is not constant for all races. It is generally higher in uni — and bivoltine races than in multivoltine races. In the former 70–80 per cent of the silk is recovered as they are less flossy and have better reelability than the latter. The pelade layer is similarly between two and four per cent of the shell weight.

It is estimated that the larva moves its head about 70 to 80 times per minute in the process of spinning the cocoon and that the bave or filament is formed at a rate of 15 cm per minute. The total length of bave in a cocoon varies from 1000 m to 2000 m in uni and bivoltine races and from 300 to 800 m in multivoltine races. The thickness of the filament is usually measured gravimetrically in terms of the denier, which is the weight in grammes of 9000 metres. The thickness is not uniform throughout but varies according to the position of the bave in the cocoon, being coarsest in the beginning and finest towards the end.

Harvesting of Cocoons

Under optimum conditions of temperature and humidity, the spinning of the cocoon is completed in 48 to 60 hrs and the larva takes another 48 to 60 hrs before it becomes a pupa. In the multivoltine cocoon producing areas harvesting on the fifth day after mounting is advocated, whereas in univoltine areas cocoons are harvested on the seventh or eighth day in spring when the temperature is between 21°C — 24°C, and in the sixth or seventh day in summer and autumn when the temperature is between 25 and 27°C. The proper time of harvesting is dependent on the condition of the pupa and so cocoons should not be harvested when the pupa inside is still amber coloured and the body is soft and fragile. In this condition the pupa is easily ruptured while handling and body fluids ooze out and damage the silk shell and spoil reelability. The proper time for harvesting is when the pupa appears dark brown in colour, slightly shrunken in size, with hard chitin and glistening eyes. Too much delay in harvesting is disadvantageous to the rearer, because the cocoons would have lost considerable weight due to continuous evaporation of body fluids of the pupa. It is also disadvantageous to the reeler because he will not get sufficient time for proper stifling of the cocoons before storage or reeling. In sericultural areas, where fly pest *Sturmia sericariae* and *Tricholyga bombycis* is prevalent, delayed harvesting may result in further disadvantage, when the cocoon shell will get pierced by the maggot that emerges nine to ten days after mounting, thus making it unsuitable for reeling. After the cocoons are harvested all the abnormal and damaged cocoons should be picked out from the sound and good quality cocoons. The bad cocoons to be excluded are double cocoons, pierced cocoons, inside-stained cocoons, outside-stained cocoons, thin cocoons, deformed cocoons, scaffolding-pressed cocoons, and too-rough-wrinkled cocoons. It is also necessary to remove the excessive floss over the cocoons and all other loosely adhering dirt matter like silkworm litter, bits of straw, threads etc. before the cocoons are taken to the market.

(ii) Physical and Commercial Characteristics of Cocoons

The cocoons have certain basic physical characteristics, some of them are commercially important as they influence the economics of reeling and the quality of the reeled product. It is therefore essential to study the physical and commercial characteristics of the cocoons.

Colour

Colour is a racial character and is due to the presence of colouring pigments in the sericin layer of the bave. It is only superficial and is removed along with sericin in the degumming process. It does not influence reeling and therefore it is not an important character to be considered for evaluation of cocoon quality. Only when purchasing stifled and stored cocoons it is necessary to consider the colour. Brightness of colour indicates that the cocoons are properly stifled and have not been too long in storage, whereas dullness shows that the cocoons have either not been properly stifled or they have been stored for too long a time.

Ordinarily the following shades of colour are found in cocoons: white, greyish white, silver white, yellow, canary yellow, sulphur yellow, old gold, pale yellow, greenish yellow and golden yellow. Distribution of pigments in the filament is, however, not uniform throughout the entire length of the bave, and varies according to breed of the silkworm producing it. In certain varieties the pigment is absent in the first 200–300 m whereas in some others the pigmentation is deeper in the beginning than towards the middle or end. In some varieties the pigmentation is peculiarly streaky. When reeling coloured cocoons, it is necessary to know the nature of pigmentation in the particular variety being reeled to forecast the colour of the reeled silk.

Shape of Cocoons

This is also a racial character but influenced to some extent by the type of mountage and care taken in management at the cocoon-spinning stage. The basic shapes are ball, egg, oval, spindle or peanut.

The shape of cocoons helps not only in discriminating the variety of cocoons but also in evaluating its reelability. The spherical, oval and moderately constricted or pointed ends reel easily, but cocoons having too deep a constriction in the middle or with too pronounced points are not suitable for steady reeling. The former has a tendency to fold up at the constricted part either in the waste removal process or in reeling, and cause the cocoon to tear or the bave to break and thus interrupt steady reeling and increase wastage of silk. The acutely pointed cocoons on the other hand develop a hole at the point in the process of brushing or later in reeling and become useless for further reeling. The pointed cocoons are also believed to contain a comparatively shorter length of silk filament.

Cocoons of the Japanese and European races are commonly oval or spherical in shape with or without a constricted girdle. Sphereical shape of cocoon is common in the Chinese race, but those of Chinese multivoltines have slightly pointed ends like a spindle. The cocoons of the bulk of Indian multivoltine races like Pure Mysore and Nistari of Bengal have slighly flattened sides and pointed ends, while the cocoons of multivoltine hybrids are oval with well rounded ends. Certain hybrid cocoons obtained by crossing the indigenous pure races with Japanese races show slight constriction also, but these variations of shapes in Indian cocoons are so slight that they do not cause difficulties or wastages in reeling.

Size of Cocoons

The size or volume of cocoon is an important character in the evaluation of cocoons. Size of the cocoon is generally indicated by the number of cocoons per litre; ordinarily the number varies between 110 and 150 with uni/bivoltine races and considerably more with multivoltine races.

Size of the cocoon generally indicates the quantity of silk filament and the percentage of silk in the cocoon and also the nature of the bave. Cocoon lots of uniform size and build would facilitate predetermining or forecasting the quality of raw silk that can be produced.

The size of the cocoon helps in deciding the cubic capacity of new installations, either for storage or for cocoon conditioning chambers. Volume has importance in areas where cocoons are sold by volume and not by weight.

Compactness or Hardness

When a cocoon is lightly pressed between the fingers,it should not yield but should feel firm, compact and slightly elastic or resilient. The extent of tightness or firmness indicates the shell texture and hardness of cocoon layer. The air and water permeability of cocoons in boiling is largely dependent on the hardness of cocoon shell. Compactness of any cocoon is however more in the middle layers than in the outer or innermost layers.

Grain or Wrinkle

The deflossed cocoon has a granular surface wrinkled with convolutions. The closeness or sparseness of the convolutions indicates the degree of granulation. The granule is coarser in the outer layer than in the inner layer.

The granulation is not uniform but varies with races as well as with conditions of rearing. Coarse granular cocoons are known to make poor reeling. They also contain bave of thicker size. Therefore, reelers prefer cocoons with finer granulations.

Weight of Cocoons

The most important commercial character of cocoons is weight. Prices are paid on the basis of weight, as weight indicates the approximate quantity of raw silk that can be reeled from it. In calculating the cost of production of raw silk, the quantity of cocoons used to produce one unit of raw silk is called *RENDITTA*, probably derived from "rendition" meaning quantity produced or rendered. The price of cocoons is adjusted according to the estimated renditta of the cocoons under transaction.

The weight of the raw or fresh cocoon is not constant but goes on decreasing till the pupa is transformed into a moth and emerges out of the cocoon. The total loss in weight, though not constant for all seasons, is about 15 per cent. This loss in weight is not sudden but occurs gradually till about a day or two prior to emergence due to natural evaporation of moisture from the body of the pupae and also due to fat consumed during the process of its metamorphosis. Hence the proper date of harvest and disposal assumes importance both in the interest of the rearer and reeler and ultimately on the quality of the raw silk.

Weight of Cocoon Shell

More important than the weight of the whole cocoon is the weight of the silk shell, as it is the shell that yields the silk for reeling. Hence, larger the weight of the shell, greater the silk yield from it. The weight is different for different varieties of breeds but, in the same breed,the weight is influenced by the care taken in rearing and mounting. In Japan the single cocoon shell weight varies from 300 to 400 mg in pure breeds and 350 to 550 mg in hybrids. In Indian multivoltine hybrids it weighs hardly 150 mg, while in the multivoltine pure races still less. Univoltine reeling cocoons reared in India produce between 200 and 300 mg of silk shell. However, the recently evolved multivoltine cocoons yield 180 to 250 mg and their hybrids from 200 to 300 mg.

Shell Ratio

As the whole cocoon with the pupa inside is purchased, it is essential to know the ratio between the weight of the silk shell and the whole weight of the cocoon. In practice this is calculated as a percentage as follows:

$$\frac{\text{Weight of the cocoon shell}}{\text{Weight of the whole cocoon}} \times 100$$

This value gives a fair indication of the quantity of raw silk that can be reeled from the lot of fresh cocoons under transaction and therefore helps in estimating renditta and fixing a proper price for the cocoons. The percentage varies with the breed of silkworms as well as the care taken in rearing and mounting. For the same cocoons, the percentage varies according to the age of cocoons due to the gradual loss in weight of the pupa.

The Indian multivoltine hybrids contain from 12 to 15 per cent while the newly evolved hybrids 16 to 19 per cent and the multivoltine pure varieties contain from 10 to 12 per cent while the Japanese reeling cocoons contain as high as 19 to 25 per cent.

Length of Silk Bave

As important as the percentage of silk shell is the length of the bave contained in the shell. This largely determines the workload, rate of production, evenness of silk thread and even the dynamometric properties.

The Indian multivoltine pure races contain from 300 to 400 m, the multivoltine hybrids from 400 to 500 m, and the newly evolved hybrids from 600 to 800 m, while the Kashmir univoltine hybrids from 800 to 1200 m, and Japanese hybrids from 1000 to 1600 m.

Weight of the Reelable Filament

The entire length of the bave forming the cocoon will not be available for reeling. The bave of the floss layer which is coarse and entangled, and the innermost pelade layer which is too thin and weak, cannot be reeled and are therefore removed. Besides these unavoidable losses, there occurs also further loss in the course of actual reeling. Considering these inevitable wastages, the actual weight and length of silk bave available for reeling raw silk will be less than the whole weight of the silk shell. Ordinarily from 80 to 90 per cent of the bave in the cocoon can be recovered in single cocoon reeling done at slow-winding speed but the percentage is considerably less in commercial reeling.

Filament Denier

Normally the denier size of the bave is higher at the beginning of the filament, i.e., the bave forming the outer floss layer, than the bave in the middle or inner layers. The pelade layer has the thinnest or lowest denier. This difference in thickness or size of the bave from the beginning to the end is so gradual and minute in mulberry cocoons that it does not interfere with the quality or the size of the ultimate raw silk reeled. However, allowing for this natural dimunition, tolerance limits are specified for the commercial raw silk as 13/15, 20/22 denier etc.

Reelability

The suitability of cocoons for economic reeling is the ease with which the cocoons yield the bave in reeling which is called the reelability of cocoons. Poor reelability causes not only haltages in production but also results in increased wastage. Hence good cocoons must have good reelability and not drop off frequently due to filament breaks. Reelability is considerably influenced by care taken during the cocoon spinning stage, and later by methods of cocoon stifling, storage, skill in processing the cocoon before reeling and the efficiency of the reeling machines and manipulative skill of the operator. Stained cocoons generally have poor reelability.

Raw Silk Percentage

This is the ultimate percentage of the quantity of raw silk reeled in relation to the quantity of fresh cocoon utilized for reeling it. Naturally, this is the most important point for consideration for a reeler because it has a direct connection with the price to be paid for cocoons and the cost of production of raw silk.

It is normally about 80–85 per cent for the whole weight of shell in well–reared univoltine reeling cocoons, and only about 55–60 per cent in the multivoltine hybrid reeling cocoons. Multivoltine pure races yield hardly 40–45 per cent.

(iii) **Defective Cocoons**

Occurrence of defective cocoons cannot be totally avoided however much care is taken in silkworm rearing. Defective cocoons are not suitable for economic reeling of raw silk and, hence a reeler prefers to purchase cocoons which are healthy and reelable and unmixed with defective cocoons. The defective cocoons are generally sorted out by the silkworm rearer himself before marketing the cocoons as the presence of defective cocoonsin a lot reduces the price.In properly reared batches there will generally not be more than ten to fifteen per cent of defective cocoons. There are fourteen types of defective cocoons but all of them may or may not be found in one lot of cocoons produced by a brood.

Immature Cocoons

This is a defect of untimely harvesting. In cold countries where univoltines are reared, harvesting is not advocated till the seventh or eighth day after mounting because the pupa until then will be tender and sensitive. In tropical countries such as India where multivoltines are reared harvesting of cocoons on the fifth day after mounting is recommended though the larva completes spinning in seventy two hours after mounting.

Black Stained

The cocoons will be dotted with black stains outside. When such cocoons are gently squeezed the pupa inside exudes a bad smell due to he putrifaction of the pupa. Such black stained cocoons mut be promptly separated from the healthy cocoons to avoid spoiling the healthy cocoons.

Rusts

Cocoons having this defect appear to have patches of rusty colour on the silk shell. The defect mainly arises from the intestinal fluid of the mature worm dropping on cocoons already formed. This produces stains of a rusty colour on the shell.

Mutes

A mute cocoon is so called because the pupa is dead and sticks to the shell inside the cocoon and therefore does not make any sound when shaken. The decaying pupa releases a putrifying body fluid which also stains the silk shell.

Spotted cocoons

These are otherwise healthy and normal cocoons on which are found spots or stains from various causes. Brownish black or yellow spots will frequently occur on fresh cocoons and even on dry cocoons when they are stored in badly ventilated and damp store rooms. The spotting in such cases is due to the development of a common green mould (a fungus of the Aspergillaceae family). Similarly spotting also occurs on dry cocoons as a result of defective ventilation of the cocoon conditioning chamber.

Thin Ends or Weak Points

This defect occurs generally at one end though the defect may occur at both ends of the cocoon. This is a serious defect because weak-end cocoons on being put into the cooking basin get water logged and become unreelable.

Undersize Cocoons

These are cocoons which are below normal in size and contain thin silk shell. Such cocoons must be separated from healthy ones and reeled separately.

Malformed Cocoons

The defect shows itself in many forms, as abnormal shapes, scaffold-pressed or cocoons having non-uniform texture of the silk shell. These cocoons would not normally be suitable for mechanical reeling.

Calcified Cocoons

Calcified cocoons are those which contain chrysalids which have been destroyed by the fungus *Botrytis bassiana*.

Loose Knit or Fragile

The loose knit cocoon is also called a straw bag and as the name indicates the shell is very loosely woven with open spaces between groups and layers making up the shell. Such cocoons are poor in silk content and easily get water-logged and become unreelable.

Fumigated Cocoons

Sometimes to check the spread of fungus causing calcification of cocoons, formalin is boiled in the mountage room. The formaldehyde fumes issuing from the boiling formalin renders sericin insoluble thereby making cooking and reeling of such cocoons both difficult and imperfect. Similarly when sulphur is burnt as a fumigant, the sulphur fumes greatly damage the silk shell and such cocoons get water logged and become unfit for reeling.

Mould

When steam stifled cocoons are stored in ill-ventilated and damp cocoon stores, they are attacked by the mould fungus. Even dry cocoons are attacked when stored in badly ventilated and damp rooms. Mouldy cocoons do not reel properly and lead to more waste.

Double Cocoons

These are large, coarse and irregular cocoons of more or less abnormal shape, which have been spun by two or occasionally more than two silkworms whose pupae naturally remain inside the same shell. Double cocoons are not really defective but they are considered so only from the point of view of the reeler of standard raw silk, because the double cocoons have shells made up of entangled silk baves which do not unravel regularly or evenly as in the ordinary healthy cocoons.

Chapter 3

THE NATURE OF THE SILK BAVE

The silk filament or bave forming the cocoon though apparently single is actually composed of two filaments or brins which issue from a pair of silk glands of the silkworm and are stuck together and covered by silk gum or sericin. The presence of gum makes the silk feel harsh and stiff. In some varieties sericin looks coloured due to a mixture of colouring pigments in it. By a process of scouring or degumming, sericin can be separated from the brins. The amount of sericin varies from 22–30 per cent according to varieties of breeds of cocoons. Silk of commercial importance should possess certain physical and chemical properties which are enumerated below:

Length of Bave

The length of bave varies with the breed of worms. Generally speaking the univoltines and the bivoltines have a total length varying from 1000 to 1400 m of which about 75–80 per cent is reelable and the rest is removed as waste. The Table below gives the cocoon characteristics of Japanese univoltines since the year 1800.

Progress of Cocoon Quality in Japan

Year	Shell ratio (%)	Filament length (m)	Reelability (%)	Non-breakable filament length (m)	Denier
1800	10.50	569	–	–	–
1918	10.36	–	–	–	–
1924	10.17	–	–	–	–
1930	10.08	–	–	–	–
1936	13.40	784	76	596	2.89
1940	14.39	913	83	758	2.69
1947	14.22	870	83	722	2.75
1952	16.24	1038	82	851	2.70
1956	16.62	1089	73	795	2.60
1962	17.31	1157	74	–	2.50
1963	17.74	1192	67	–	2.57
1964	18.14	1215	77	–	2.67
1965	18.45	1243	68	–	2.71
1966	18.33	1211	68	–	2.68
1967	18.94	1222	73	–	2.70
1968	18.95	1250	71	–	2.70
1969	18.85	1253	72	–	2.75
1970	19 to 25	900–1400	73	–	2 to 3.0

The multivoltine pure races are poor silk yielders and build flossy cocoons which contain only about 350 to 600 m of which hardly 50 per cent is reelable. On the other hand, newly evolved multivoltine hybrids obtained through breeding experiments produce better cocoons with longer length of bave between 500 to 800 m of which over 60 per cent can be reeled.

The cocoon characteristics of certain Indian silkworm races are as follows:

Race	Shell ratio (%)	Filament length (m)	Denier
1. Pure Mysore	12–14	300–400	1.8 or 2.0
2. Nistari	11–13	300–350	1.8 or 2.0
3. Mysore hybrid	13–15	400–550	2.0 or 2.2
4. New multivoltine hybrids of India	15–17	600–800	2.2 or 2.6
5. Pure uni/bivoltine stocks in India	16–19	800–1000	2.0 or 2.4
6. New hybrids of uni/ bivoltines	20–22	1000–1500	2.6 or 3.0

Size of Bave

The size of the silk thread, bave or reeled raw silk, is expressed by the term denier. A denier is the weight of a length of 450 metres in 0.05 g units or the weight in one gramme units of a length of 9000 metres. Thus if a sample of 450 m weighs 0.05 g or a sample of 9000 m weighs one gramme, each sample is said to be one denier in size. The size of the bave is not constant throughout its great length but varies according to its position in the cocoon shell. The portion of bave forming the floss and outer covering of the shell is thicker than the bave of the middle compact reelable shell and the bave forming the inner most pelade layer. When denier of successive short lengths of the bave are taken from the beginning to the end, it is seen that the dimunition in size is not sudden but very gradual and that the bave can be likened to an enormously stretched cone. Although the general tendency is gradual dimunition in size, even in any short segment sudden thicknesses of the bave frequently occur due to uneven and lumpy distribution of the sericin. The dimunition in size is not serious in reeling firstly because the coarse bave of the floss and the too fine bave of the pelade are not used for reeling but are removed as waste; and secondly the dimunition in size of the reelable portion is very slight and extended over a great length. The average diameter of the bave is 15–20 microns for the univoltine and bivoltine races whereas for multivoltine races it is 6–14 microns. As the denier of bave is approximately proportional to the mean diameter of the bave, the uni–and bivoltines have generally larger denier than the multivoltine varieties.

Microscopic Examination of the Bave

The longitudian view of the bave shows that the surface of the sericin layer is irregular and lumpy in places. Even under the covering of sericin, the inner brins can be seen as two smooth and transparent cylinders of fairly uniform thickness. Frequently the two brins are clearly separated for considerable lengths though the intervening spaces are filled with sericin.

In cross section, the shape of the bave is not uniform. The bave from the floss layer is slightly elliptical whereas that from the middle compact shell, which is reeled, is more circular. The bave from the pelade is fine in size and distinctly flat and ribbon like. The enclosed brins, however, appear as equilateral triangles with rounded off angles, facing each other at their flat sides.

In the longtitudinal view, the degummed bave shows two brins as lustrous, compact and homogeneous rods of more or less constant thickness. When the brins are soaked in a 2.5% solution of sodium hydroxide

for twenty four hours (Fig. 3, 4 and 5) and later the fibre is crushed, the fibre is seen to break up into a number of minute fibrils, thus indicating that the apparently structureless brin is fibrillous in structure. The thickness of each fibril is about one twentieth of the normal filament or less than one micron. The fibrils run parallel to the axis of the fibre. In certain silkworm varieties which produce thick baves, the fibre splits into its constituent fibrils which stand out from the main fibre as minute hairs. The appearance of hair-like projections of the fibre is known as lousiness. Lousiness is more frequent in the middle layer of the cocoon shell and least in the inner most layer. It is also more frequent in baves produced by worms which have been overfed in their fifth stage. The other cause of lousiness is mounting of over-mature larvae. The defect of lousiness is less in breeds of silkworms which spin finer bave.

The characters of size and shape of the brins are important to the manufacturers of silk fabrics because it is on these qualities that the effect of dyeing depends. Yarn made from large diameter brins, or those flatter in cross section, dye darker than those from smaller brins with nearly rounded cross section. Lousiness is a serious problem to the manufacturers of all fabrics particularly smooth satins and neck-tie material because, when fabrics woven with such silk are dyed, they appear as if lightly covered by dust or show a paler shade than the main fabric due to the greater transparency of the protruding fibril and its smaller absorption capacity for dyes. Lousiness does not usually become a problem if the occurrence of projecting fibrils does not exceed 100 to 150 per 1000 m of thread.

X-ray of Silk

X-ray photographs show definite X-ray spots, which indicate that fibroin is crystalline in structure. The crystals are less than one tenth of a micron long and a few thousandths of a micron thick. A single fibre is therefore made up of an incredibly large number of crystals with the result the sum total of all the surface area of the crystals is very much more than the outer visible surface of the fibre. It is for this reason that silk has a great water absorption quality. When water has been absorbed the silk swells appreciably to the extent of nearly 33 per cent of its original thickness but the extension or lengthening of the fibre is not as conspicuous because the crystals are more than twenty times longer than their thickness.

Hygroscopic Nature

Hygroscopic properties of raw silk are commercially very important. Silk is very hygroscopic and is capable of absorbing up to 30 per cent of its weight of moisture, when exposed to saturated conditions of atmosphere without feeling wet or dry. But when bone dry silk is kept for a specified time in a standard atmosphere having 65 per cent humidity at 25^{0}C, the silk absorbs only 11 percent of its weight if the silk is raw and 10 per cent if it is in degummed condition. This is the accepted moisture regain coefficient of silk, and mercantile weight of silk is calculated accordingly.

Tensile Strength

Silk has enormous tensile strength with a breaking load of nearly 5000 kg per cm^2 or as much as 4 g per denier. It has an elongation of about 20 per cent of its original length before breaking. The elasticity is relatively less. It can be stretched only one to two per cent before it has a permanent set. Excess moisture increases the weight and elasticity of silk but decreases its breaking strength.

Tenacity of silk varies with the breeds of cocoons and, in the same cocoon, the tenacity per denier increases from the exterior to the interior of the cocoon while the elasticity varies inversely. Degummed bave has greater tenacity than raw bave.

Density of Silk

Raw silk has a density of 1.33where as degummed silk has a density of 1.25.Although these are the accepted standards of density, it is not absolutely constant for all varieties of silk but within small limits it varies with the breed of cocoons. About 65 per cent of the volume of silk is solid and about 35 per cent vacuoles.

Degumming Losses

Sericin which is the soluble portion of the bave forms between 22–30 per cent of the whole weight. As sericin is unevenly distributed in the bave, the percentage of loss is not uniform in all segments of the bave.

Scroop

Another property of silk which is peculiar to the fibre is its "scroop". This refers to the crackling sound emitted when the fibre is squeezed or pressed. The well known "rustle" of silk fabrics is due to the property of scroop. The scroop of silk however is not considered as an inherent property but rather acquired in the manufacturing process by treating in a bath of dilute acetic or tartaric acid and drying without washing.

Electrical Properties

Silk is a poor conductor of electricity and accumulates a static charge by friction, which at times renders it difficult to handle in the manufacturing process. The charge can be dissipated by high humidity or by maintaining 65 per cent R.H. at 25^{0}C. Owing to its insulating properties silk is extensively used for covering wire in electrical apparatus.

Effect of Light

Silk is sensitive to weakening by ultra violet light. It loses as much as 50 per cent of its strength after six hours exposure to ultra violet light. Scoured silk requires a much shorter time for tendering. Silk in the form of fabric is readily damaged by sunlight.

Effect of Heat

If white silk is heated in an oven at 110.5^{0}C for 15 minutes it begins to turn yellow. Above 170^{0}C silk disintegrates and on burning, it gives out an empyreumatic odour.

Action of Water

Water does not permanently affect silk fibre. Its strength decreases about 20 per cent when wet but regains the original strength upon drying. The fibre swells, but does not dissolve when steeped in warm water.

Silk is a highly absorbent fibre and readily becomes impregnated with water. Dissolved substances present in the water are also absorbed along with the water. It is for this reason that considerable importance is given to the quality of water for reeling, washing, dyeing or finishing. In most modern silk mills water is softened by the zeolite process and the hardness reduced practically to zero.

Action of Acids

Concentrated sulphuric and hydrochloric acids dissolve silk. In strong hydrochloric acid silk is dissolved in one or two minutes. Sulphuric acid takes a much longer time. If silk is treated with strong sulphuric acid for only a few minutes, then rinsed and neutralized, the fibre contracts from 30 to 50 per cent in length and loses its lustre, and no further damage is done. This is taken advantage of in creping of silk fabrics. Similarly when silk is treated with dilute hydrochloric acid having a density of 29^{0}Tw, it shrinks without suffering any loss of strength. This is advantageously used for producing creping effects. Nitric acid and orthophosphoric acid may also be used for creping silk material.

The action of nitric acid is peculair as it produces a bright yellow colour on silk which can be removed by treatment with a boiling solution of stannous chloride. But when silk is treated for one minute with nitric acid of sp. gr. 1.33 at a temperature of 45°C, the silk acquires a bright yellow colour which is permanent and fast also to light. This yellow nitro–silk can be further brightened by treatment with an alkali. With strong sulphuric acid nitro–silk swells and becomes a gelatinous mass resembling egg albumen.

Reaction of silk to tannic acid is somewhat like hide in that it absorbs a large amount of tannic acid from a cold solution and as much as 25 per cent of its own weight from a hot solution. The tannin so absorbed is not readily removed by treatment with water.Tannic acid is used as a mordant in weighting of silk.

Formic acid and acetic acid have no injurious effect on silk unless heated. When silk is treated at ordinary temperature with 90 per cent formic acid, it swells, contracts and becomes gelatinous in about two to three minutes. When silk in this condition is rinsed in water it returns more or less to its original condition and on drying becomes stiffer and more lustrous, without loss of tensile strength. This method is sometimes used for improving the lusture of inferior silks but the disagreeable new lustre and the general tendering of silk in the process are against more popular use of the method.

Perspiration greatly tenders silk especially if the silk is weighted. Deodrants containing aluminium chloride render perspiration alkaline and thus cause perspiration tendering of worn silk material.

Action of Alkalies

Silk is not sensitive to dilute alkalies, though the lusture of the fibre is somewhat dulled. When treated with strong hot alkalies such as caustic soda or caustic potash, silk fibre dissolves. Ammonia and alkaline soaps dissolve only the sericin layer of silk but have no effect on the fibroin. Continued boiling in such soaps for a prolonged period, however, affects fibroin. Borax has no action on either sericin or fibroin. If raw silk is steeped in lime water, the fibre swells to some extent and the sericin becomes soft. Continued treatment with lime water would render silk brittle. Ammoniacal solutions of copper and nickel salts are good solvents for silk. The nickel compound is sometimes used to separate this fibre from cotton.

Action of Metallic Salts

Silk has great affinity for metallic salts. This characteristic is the basis for the process of silk weighting, as it is claimed to improve draping properties of the fabric. Stannic chloride is commonly used for weighting unless the material is to be dyed black. From eight to ten per cent of tin salt is absorbed from a cold solution of stannic chloride. This amount of weighting does not injure the material but tends to increase the breaking strength.

Black silk is often dyed and weighted by using log–wood and iron salt. If the weighting has been properly done, slightly more than one fourth of the weight lost in degumming may be added without noticeable injury to the fabrics.

Action of Dye Stuffs

Silk has a greater affinity for dye than any other textile fibre. It absorbs dyes at a low temperature, and, being a protein, it possesses both acid and basic properties and therefore can be dyed with basic or acid dyes.

Acid colours are dyed in strong acid baths some of which are fast to light and others fast to washing. Direct colours are used to dye silk preferably in neutral or weak alkaline solutions. Basic colours may be dyed in either weak acid, neutral or slightly alkaline solutions. Vat colours are soluble only in fairly strong alkaline solutions, but alkalinity should be kept as low as possible to dissolve the dye stuff.

Chapter 4

COCOON AS RAW MATERIAL

(i) Selection of Raw Material for Reeling

Selection of cocoons must be done very carefuly as any carelessness in this respect would spell serious losses to the reeling enterprise. Selective purchase of cocoons in an open market is extremely difficult, and becomes imperfect particularly in the absence of determined standards of quality for cocoons, and standard methods of testing for classifying cocoons into quality grades. In sericulturally advanced countries, on the other hand, where the cocoons produced are of good and uniform quality, the cocoon trade has been systematised to a large extent by the introduction of standards of quality for cocoons and uniform methods of cocoon testing which includes test reeling.

In countries where inferior quality multivoltine race cocoons are produced and where reeling is mostly practised as a cottage industry with small installations, elaborate methods of testing of cocoons prior to transaction are not used. Estimating quality of cocoons under transaction is mostly by application of empirical methods, derived from generations of experience in the cocoon trade and reeling industry. This system although not infalliable, nevertheless works satisfactorily as the reeling industry is not as sophisticated as in sericulturally advanced countries and continues to depend upon the intelligent observations and manipulative skill of purchases. The method adopted consists of preliminary enquiries, visual examination, tactile and numerical tests.

Preliminary Enquiries

The regional and seasonal variations have appreciable influence on the quality of cocoons. Similarly good quality seed is of basic importance in obtaining proper harvests of superior quality cocoons. This directly helps in estimating the quality of cocoons harvested. The quantity and quality of cocoons harvested depend also on the equipment and care taken during rearing and mounting. Date of mounting is likewise important as it would indicate the age of cocoons at the time of harvest. Immature cocoons are not preferred by reelers because they would have pupae with excessive moisture affecting the percentage of silk yield. Further, as the pupal chitin would be too fragile, the reelability would also suffer in subsequent handling which may result in high costs of production.

Visual Examination of Cocoons

The lot of cocoons under transaction is critically scanned to see whether it contains 'melted cocoons'. The presence of these can be ascertained by the putrid smell emanating from the pile of cocoons. This is confirmed by carefully thrusting the open palm into the pile. Melted cocoons are not desired as they are poor in reelability, and it is difficult to preserve them in storage. Melted cocoons occur when live cocoons are kept heaped for too long a time without proper aeration.

The cocoons will be uniform if good seed has been used and rearing attended to properly. Wide variations in shape and size of cocoons would indicate that either the seed used was bad or the rearing had not been carried out properly or the lot under transaction was a mixture of small lots collected from different sources; these cause reeling difficulties and also increase cost of production.

Cocoons affected by liquid excreta of the silkworms are deeply stained and such cocoons are known as urinated cocoons. These have poor reelability and are uneconomic for reeling and, therefore,fetch lower price than normal cocoons. During the rainy season the incidence of urinated cocoons is somewhat higher and the careful purchaser is particularly wary in evaluating cocoons during this season.

Cocoons should not be too flossy. Floss merely adds to the weight of cocoons when yielding silk for reeling. Cocoons should have well-rounded and firm ends and must not have too pronounced points. Well-pointed ends are easy to detect because of their shape; thin ends can be detected by the lighter shade of colour at the end which when pressed yields readily. When floss is peeled off the cocoons, the surface must be fine grained and not deeply wrinkled.

Tactile and Numerical Tests

When the palm is thrust into a heap of cocoons, if it feels cool and moist, it is considered that the lot contains immature cocoons. Such cocoons when shaken close to the ear make a muffled thudding sound instead of a rattling sound made by the mature cocoons. When no sound is made, cocoons are reckoned to have dead pupae sticking to the shell inside. As regards the feel, the cocoons should feel firm and full when they are gently squeezed in the palm.

The actual number of cocoons in a kilogram in the lot is counted to find the average weight of individual cocoons. Usually fifth-day harvested commercial crop cocoons in multivoltine races, count between 1000 and 1500 per kilogramme whereas uni/bivoltine races range between 600 and 800. The lower the number of cocoons, the greater their silk contents.

The final valuation of the cocoons, however, is made only after assessing the unreelable and double cocoons found mixed in a lot. The price fixing for cocoons is done generally in the context of ruling prices of raw silk in the market.

(ii) Scientific Method of Cocoon Testing and Classification

In Japan on the other hand, the importance of testing and classification of cocoons into quality grades is so fully realised that a law called "the silkworm cocoon inspection law" has been introduced to enforce cocoon grading before transacting. This law is amended whenever necessary. The operation of this law is made easy and effective, firstly by regionalising the cocoon producing areas and secondly by establishing in each region a required number of cocoon-testing stations. Cocoon transactions are done through organized sericultural co-operatives, where the cocoons are sold by sericulturists at prices settled in accordance with the cocoon test certificate issued by the cocoon-testing station concerned.

The cocoon testing and grading centres strictly follow the standards and procedures as specified by the cocoon testing regulations in force at the time. Testing is done on joint application by the transacting parties, sericulturist and reeler. Cocoon samples in specified quantities are taken from the lots, by the official of the testing station in the presence of the transacting parties. The samples are drawn at random from different parts of the lot so that the total sample drawn truly represents the entire lot. The quantity of cocoons to be drawn as sample is specified as follows:

A. For fresh cocoons

gross weight of the lot	wt. of sample to be drawn
2 250 kg	4.5 kg
4 500 kg	6.0 kg
above 4 500 kg	7.5 kg

B. For dry cocoons

825 kg	1.8 kg
1 650 kg	2.4 kg
above 1 650 kg	3.0 kg

The samples so drawn are weighed in the presence of the parties concerned and kept separately in bags until taken for testing. In order to avoid delay in transactions pending the supply of test report, the cocoon producer is permitted to deliver the cocoons after the samples have been taken to the reeler and accept an advance payment from the reeler on the basis of the minimum price expected for the lot. The final adjustment, however, is made only after the cocoon test report is made available.

After recording the weight of the samples, the cocoons are sorted into reelable and unreelable cocoons. The unreelable cocoons are picked out from the lot by comparison with the standard samples of defective cocoons supplied from time to time by the Ministry of Agriculture and Forestry. Several types of defective, sorted and rejected cocoons for reeling are:

(1) Double cocoons
(2) Cocoons pierced by the maggot of the fly pest
(3) Cocoons stained from inside
(4) Outside stained cocoons
(5) Cocoons with thin ends
(6) Flimsy cocoons
(7) Malformed cocoons
(8) Excessively flossy cocoons
(9) Double layered cocoons
(10) Cocoons having too thin a layer in their constricted or waist part.

The percentage of each of these is separately calculated and recorded and the percentage of cocoons actually available for reeling is obtained. One third of the reelable cocoons are retained for test reeling and the remaining used for testing of the following items:

(i) **Size of the cocoons**

This is indicated by the number of cocoons of a particular race in one litre, generally from 110 to 150. Smaller cocoons are preferred as they contain a larger percentage of silk and the cocoon filament is smaller in denier size.

(ii) **Compactness**

Cocoons should be firm and not yield to slight pressure.This quality ensures more efficient mechanical processes in reeling and reduced wastage.

(iii) **Grain or wrinkle**

Very rough grained cocoons are considered unsuitable for reeling. Depending upon the degree of grains, the results are recorded as excellent/first/second/third/fourth class.

(iv) **Weight of cocoons**

Cocoons though small in size should weigh more as it indicates the quantity of silk contained in them. Usually one litre of cocoons weighs about 150 to 200 g.

(v) **Weight of silk shell**

It varies between 350 and 550 mg and about 80 per cent of this quantity is available for reeling.

(vi) **Percentage of silk shell**

The silk shell should have less of floss and more of reelable silk. It is generally between 14 and 20 per cent for multivoltine and univoltine races respectively.

After these tests are conducted and the results are recorded, the reserved cocoons are put through actual reeling tests. In the past, multi-end reeling machines with ten ends were used for this purpose and reeling was done at a speed of 80 m per minute. In some grading stations, direct reeling machines were also used. Cocoons are cooked in the ordinary open pan or in a Central Cocoon Boiling machine by expert operatives. At present a four-end ordinary sitting type or six-end automatic reeling basin is generally used for test reeling. The thread speed is adjustable from 150-210m per minute. Generally seven cocoons are taken at each end for reeling. If the cocoons drop off too frequently the speed is adjusted. Results are calculated and recorded on the following items.

Average Length of Reelable Cocoon Filament

This is calculated on the total length of reeled silk and the actual number of filament casting required for reeling it. The workload and efficiency of reeling as well as the evenness of reeled silk depend upon the average length of unbroken filament actually available for reeling. Longer length means better reeling efficiency and more even size of silk.

Reelability Ratio

This ratio is calculated from the number of times of casting filaments and the number of cocoons reeled, and expresses the frequency of breakages of cocoon filament during reeling. Frequency must be less for economic reeling.

Denier of Cocoon Filament

The size or the denier of silk thread is measured gravimetrically by taking a constant length of 450 m and weighing it in units of denier 0.05 g or for convenience 9000 mts in gramme units. In practice it is calculated as follows:

$$\frac{\text{Wt. of reeled silk}}{\text{Length of reeled silk}} \times 9000 = \text{The denier size of reeled thread}$$

This value is very important as it indicates the number of cocoon filaments to be assembled for obtaining the required size of reeled silk. It further indicates the quantity of reeled silk that can be expected in a unit time.

Quantity of Reelable Cocoon Filament

This is the weight of cocoon filament per casting and is related, therefore, to the reeling efficiency and eveness quality of the reeled thread.

Raw Silk Percentage

This value indicates the cost of cocoons in the overall cost structure of the reeled silk and therefore directly helps in fixing the price to be paid for the cocoons.

Neatness Defects

The number of small knots and loops, their size and frequency of distribution on the raw silk are represented in percentage by comparing the sample of 20 panels taken on the seriplane board, with the standard photographs for neatness defects. The neatness of the raw silk determines the quality of the finished woven fabrics. Silk thread should have minimum neatness defects.

The values obtained from the above tests help in estimating the quantity and quality of the raw silk that can be obtained from the lot concerned.

The following illustration emphasises the practical importance of the items enumerated above:

Sample: 300 cocoons are taken at random from a lot of reeling cocoons of spring season for testing.

Procedure: The cocoons are first boiled in the Central Boiling machine, after preliminary examination of the lot for irregular/deformed cocoons or cocoons with dead pupae inside.

According to the standard method of cooking in use, the cocoons reach a satisfactory sunken stage in 11 minutes. The boiled cocoons are then passed on to the test reeling section.

Equipment: Six ends automatic reeling machine:

There are three meters mounted on the machine at appropriate places to record
(i) length of reeled silk on a reel (ii) number of droppings and (iii) number of cocoons at each end in the reeling platform of six ends.

Size reeled: 20/22

Number of cocoons per end to start with: 7

Time taken for reeling the spring lot under test: 78 minutes

The reeling is continued until 250 cocoons are completely reeled. At the end of reeling, the unreeled cocoons in different stages: partly reeled, half reeled, more than 75 percent reeled etc., are taken into consideration and equated to full unused cocoons after applying the correction factor, as detailed below.

In the given sample the remnants or the left-over cocoons are as follows:

1. Full cocoons boiled but not reeled: 2
2. 50 per cent reeled cocoons:20
3. 30 per cent reeled cocoons:22
4. 20 per cent reeled cocoons:10

The correction factors have been prepared and a reckoner to each test reeling assistant to arrive at the full unutilised cocoons to be deducted from the number of cocoons taken for test purposes. Two sets of tables are used for application and assessment of filament length and shell weight; for example:

(i) For calculating the filament length

20 x 0.85	17.00
22 x 0.37	8.14
10 x 0.11	1.1
	27.24 or
	27 cocoons

(ii) For calculating weight of reeled silk

20 x 0.80	16.00
22 x 0.28	6.16
10 x 0.06	0.60
	22.76 or
	23 cocoons

No. of cocoons actually used up:

(i) 300 — (27 + 2) = 271 (ii) 300 — (23 + 2) = 275

Observations

The test results enumerated below serve to focus attention on the various characteristics taken into consideration for assessing the quality of cocoons:

1.	No. of dried cocoons in a test sample:	300
2.	Weight of the cocoons:	289 g
3.	No. of cocoons found unutilised for assessing filament length:	29
4.	No. of cocoons unutilised out of the sample for assessing weight of reeled silk:	25
5.	No. of cocoons unutilised out of the sample for assessing reelability:	27
6.	No. of cocoons reeled out of the sample (300 — 29):	271
7.	No. of cocoons out of the sample considered reeled for assessing the weight of reeled silk:	275
8.	No. of cocoons out of the sample considered reeled for assesing the reelability of the lot:	273
9.	Effective number of cocoons casts:	328
10.	Length of reeled silk:	48 291 m
11.	Length of total filament reeled out of the sample 48 291 x 7.54 — No. of cocoons per end:	364 114 m
12.	Percentage of raw silk:	44.19
13.	Weight of reeled silk:	117.84 g
14.	Weight of single cocoon shell:	429 mg
15.	Filament length $\frac{364114}{271}$	1 344 m
16.	Size of filament length $\frac{117.84 \times 9000}{364114}$	2.91 denier
17.	Non-breakable filament length: $1344 \times \frac{83.2}{100}$	1 118m

Classification of Cocoons

According to the testing regulations, cocoon classification is done on the basis of quality and reelability grades. Quality grade of raw silk is mostly determined by the unformity in size of the thread and by the frequency of distribution of knots in it, though in practice the degree of evenness is the deciding factor in grading raw silk. Hence in evaluating the quality of cocoons, priority is given to the length of silk bave available per casting, as longer length ensures better evenness. Next, the denier size of the bave is considered as it determines the size deviation in raw silk;the higher the denier of the bave the greater will be the size deviation with consequent impairment of silk quality. It is for this reason that cocoons of small but suitably sized bave are used for reeling with a fixed number of cocoons, as they make the degree of evenness higher. Hence the original estimation on length is suitably adjusted according to the denier size of cocoon filament for every 0.5 denier. Even if the reelable length of cocoon bave is the same in two samples, the samples showing better reelability is preferred as it makes for a higher degree of evenness and reduces workload on reeler. So from the previous valuation, a further adjustment of $\pm$ 0.5 is made on the basis of reelability.

As the uniformity of size and shape of the cocoons influences the size deviation of raw silk, further adjustment as + or — is made according to the excellent/ first/ second/ third/ or **fourth** class. The final estimation after these adjustments is called the cocoon quality mark. On the basis of this quality mark and the estimation of neatness defects, cocoons are classified into ten grades as follows:

Length (m)	890	891–960	961–1030	1031–1100	1101–1170	1171–1240	1241–1310	1311–1390	1391–1450	1451 and above
Points	38.0	38.5	39.0	39.5	40.0	40.5	41.0	41.5	42.0	42.5
Reeling quality	less than 49%	50–56%	57–63%	64–68%	69–73%	74–78%	79–82%	83–86%	87–90%	More than 91%
Points	47.0	47.5	48.0	48.5	49.0	49.5	50.0	50.5	51.0	51.5

(iii) Price Fixing

The price of cocoons is calculated by multiplying the raw silk percentage by a coeficient known as kakeme or kake. Kakeme means the price in yen of that quantity of fresh cocoons required to produce 3.759 kg of raw silk, which unit in Japan is called one kan and forms 1/16th part of a picul* of raw silk contained in bale. Kakame is calculated as follows:

(Price of raw silk + income from by-products) — (Cost of production + expected profit) divided by 3.759

The above calculation gives the total price to be paid for cocoons required for producing one kan (3.759 kg) of raw silk.

In practice, the average yield of raw silk is taken at 10 per cent of the fresh weight of cocoons and the standard basic price line per kan is determined according to the above formulae. Keeping this as the base price line, the actual price of cocoons under transaction according to their quality is determined by adding or deducting to or from the standard kakeme calculated on the basis of quality grade and reelability grade. Kakeme is directly proportional to higher price of raw silk as well as higher grade of reelability of cocoons. The addition or deduction is made according to the difference of every one grade in quality or reelability grade. This adjustment is called kakusa and is determined by agreement between cocoon producers and reelers.

(iv) Stifling and Conditioning of Cocoons

Cocoons in their fresh condition with the pupae alive in them cannot be stored for a long time as the living pupae are soon transformed into moths — generally within eight to ten days in a warm climate and ten to twenty days in a very cold climate — which emerge from the cocoons by piercing the shell through one end. Cocoons from which moths have emerged are called pierced cocoons. They are useless for reeling raw silk because the continuity of the bave in them is broken. Reeling cocoons, therefore, have to be subjected to a process of stifling with the object of killing the pupae inside without in anyway interfering with the structure of the silk shell around it.Cocoons can be stifled by several methods but the popular methods in reeling industry are sun drying, steam stifling and hot air conditioning.

*1 picul = approx. 60 kg

(a) Sun drying

Sun drying consists in killing and drying the pupae by prolonged exposure of freshly harvested cocoons to scorching hot sun. The cocoons so treated can be preserved for any length of time without fear of moth emergence or their deterioration by any means. The method is simple. Immediately after the harvest of cocoons they are thinly spread out on mats and kept in the hot sun from sunrise to sunset every day for several days till the pupae are killed and the cocoons completely dried. Sun dried cocoons are very light and when shaken make a rattling sound.

Although sundrying is simple and cheap, it is not suitable for modern reeling. Sun drying is possible only when there is bright and hot sunlight continuously for several days soon after cocoon harvest. Silk is very sensitive to sunlight and when cocoons are exposed to action of bright and hot sunlight for a prolonged period as in the sundrying process, the original strength of the bave is very much affected impairing reelability of the cocoons and injuring the quality besides increasing wastage of silk in reeling. It has been proved conclusively that silk suffers a high rate of tendering when exposed to sunlight on account of the action of ultra violet rays. Sundrying itself is cumbersome and wasteful in space and labour. However, in spite of these shortcomings, sundrying continues to be practised in those areas lacking alternative methods of stifling the cocoons economically.

(b) Steam Stifling

Steam stifling means killing the pupa in the cocoon by exposing the freshcocoons to the direct action of very hot wet steam for the required period. It is done in small containers if the quantity of cocoons to be stifled is small; if large, stifling is done in specially designed chambers supplied with steam from steam generating boilers.

Basket Steaming

In small reeling establishments, which handle only small quantities of cocoons at a time, fresh cocoons are stifled in a simple manner. About 10–15 kg of fresh cocoons, from which all the obviously defective cocoons have been picked out, are loosely filled in a basket woven of bamboo, or any other suitable material, (Fig. 6) in which the sides are closely woven but the bottom is loosely woven so as to allow steam to pass through easily. A thick wet cloth is then tightly stretched over the top of the basket, and tied at the sides leaving the bottom free. The basket thus filled with cocoons is placed over the mouth of a vessel in which water is boiled. Sometimes the reeling basin itself is used for this purpose as in the case of Indian Charkas. The hot steam from the vessel below soon fills the basket and stifles the pupae in the cocoons and kills them in about half an hour. Steaming is stopped when dense steam starts coming out of the basket through the sides of the basket and emits a smell peculiar to the freshly steamed cocoons.

When the open palm is lightly placed on the freshly steamed cocoons, the cocoons feel hot, damp, slimy and sticky. The cocoons yield even under slight pressure between the fingers because the cocoons will be soft and wet due to the steaming. Cocoons in this condition are reckoned to be properly stifled. But in order to make sure that the stifling has been effectively done, a few cocoons of good build or double cocoons are picked out from the freshly steamed cocoons still in the basket, their shells are cut open and pupae placed on the open palm and examined to see if they are killed. If the stifling is not thorough, they will be still alive and promptly react to the exposure to cold air and start wriggling. In such an event, the steaming is continued for some more time. The freshly steamed cocoons are then poured out and thinly spread on mats for airing in the shade for several hours till the cocoons feel dry, firm and cool and no

longer sticky. Wet cocoons are not stored, as they are easily attacked by fungus. Freshly steamed cocoons are not suitable for immediate reeling because the sericin will be too soft and dissolves readily in cooking and reeling baths, and the silk bave instead of unravelling steadily will come off in lumps and spoil the quality of the reeled silk. The freshly steamed cocoons are kept, therefore, in the shade atleast for three to four days to allow the damp or wet sericin to dry set and the cocoon will become firm and fit for reeling. This is known as seasoning of the cocoons.

If the steamed cocoons are required to be stored for a very long time, they are thinly spread out in trays and placed in well ventilated rooms for several days for drying till the weight of the cocoons is reduced to about one third the original weight of fresh cocoons. During this process, additional labour is employed for frequent turning of the cocoons to ensure uniform drying and also to prevent fungus attack. Inspite of the best care taken, the cocoons are prone to damage in handling.

Barrel Steaming

Sometimes instead of the bamboo basket, a convenient sized metal barrel is used for steaming. The barrel which is permanently fixed over an oven is provided with a platform inside on the bottom plate on which is kept the basket filled with fresh cocoons for steaming.The barrel is also provided with a close fitting lid to cover the barrel when steaming is in progress.

Water is poured into the barrel to about two thirds height of the platform and boiled over a fire in the oven below. When the water starts steaming, the basket loaded with about 15–20 kg of fresh cocoons is placed on the platform in the barrel and the barrel lid securely closed to prevent escape of steam. Due to increasing temperature and pressure of steam building up, cocoons are stifled in ten to fifteen minutes.

Chamber Steaming

In large reeling organizations which buy very large quantities of cocoons not only for day–to–day use, but also for holding over reserve stocks, specially designed and conveniently large sized chambers are constructed for steaming the cocoons. These chambers are internally provided with perforated steam pipes (Fig. 7) which are connected inside to the steam supply pipe from the steam boiler. In some types of chambers, shelves for keeping the fresh cocoons are permanently fixed while in certain other types, the chambers are provided with movable shelves on wheels.

In the fixed–shelf type, the trays filled with fresh cocoons are placed in the shelves and after closing the chamber door, the steam under pressure is let into the chamber by opening the steam valve provided outside the chamber. After about fifteen to twenty minutes, the steam supply is shut off, the chamber door opened and the cocoon trays removed for airing. The next load of fresh cocoon trays will be kept in the vacated shelves in the chamber and the steaming process repeated.

In the other type of chamber provided with movable shelves on wheels, the process of steaming can be made more or less continuous with very little wastage of time between discharge of steamed cocoons and the reloading of fresh cocoons in the chamber, by providing a set of two trolley–shelves for each chamber. When one shelf carrying the fresh cocoon trays is being steamed, the other similar trolley shelf waiting outside could be kept charged with fresh cocoon trays to be pushed into the steaming chamber immediately the first trolley is drawn out.

Disadvantages of Steam Stifling

Steam stifling of cocoons has certain drawbacks. Steam stifling only kills the pupa inside and does not dry it. The pupa normally contains moisture in the form of body fluids, to the extent of nearly 65 per cent of its own weight. This large moisture content makes the pupa fragile and weak, and so such cocoons cannot be kept stored in thick layers, because of the risk of the pupae in the lower layers getting crushed under the weight of the cocoons above and the body fluids spoiling the silk of the cocoons. Steamed

cocoons, therefore, are spread in thin layers in trays and the trays kept in shelves with sufficient space between them for satisfactory aeration of cocoons. In addition to this elaborate arrangement, additional labour is employed for giving frequent turnings to the cocoons in storage in order to prevent mould attack and to ensure uniform and quick drying. In spite of the care taken, often humidity in the store room increases due to natural evaporation of the moisture from the pupae and as a result, conditions favourable for formation of mould on the stored cocoons are created. This is really a serious problem specially during the rainy season. Further, the damaged wet pupae decompose rapidly and stain the silk shell, and damage the reeling properties of the cocoons. Prolonged exposure of fresh cocoons to wet hot steam also denatures sericin in the cocoon and consequently alters the behaviour of cocoons in the cooking process and later in the reeling process, resulting in increased silk wastage and spoilage of the quality of reeled silk in respect of cleanness. Steamed cocoons cannot be reeled immediately after steaming because the sericin will be wet, hot swollen and soft. Cocoons reeled in this condition lead to too much wastage of silk in cooking and reeling, and cleanness defects also increase in the raw silk reeled. Hence the steamed cocoons are aired at least for two to three days for seasoning before storing.

In the sericulturally advanced countries, stifling of cocoons by steam has been largely replaced by hot air which also dries the stifled cocoons, in all the modern silk reeling factories. This method of stifling and drying the cocoons is known as hot air conditioning. Hot air conditioning is carried out in chambers of special design for a required period with the object of killing the pupae and drying it either fully or partially to the desired degree of dryness.

(c) Evolution of Hot Air Dryer

An old type of hot air conditioning equipment consisted of three functional parts, a long rectangular wooden box for keeping the fresh cocoons for drying, an air heating equipment of simple design and a blower or fan operated by hand or driven by motor, (Fig. 8). These parts were connected by ducts to obtain continuous air flow from the blower to the exit of the cocoon drying chamber. This equipment was inadequate for the purpose of satisfactory conditioning because it lacked the necessary adjustments for controlling temperature and air flow, and also for making the process continuous. In the subsequent models, some of these deficiencies were overcome.

One such equipment consists of a tall rectangular chamber of masonry with white cement plastering inside or a chamber of pressed metallic plates lined inside with asbestos sheets. Internally this chamber is sub-divided into five compartments of equal size one below the other. The first four compartments in the descending order are separated from each other by means of sliding wiremesh screens with a handle outside the chamber so that they can be pulled out and pushed back into position as required (Fig. 9). The fourth and the fifth chambers are similarly separated but by a fixed wiremesh screen. The chamber immediately above the lowest chamber is provided with a door on one side to enable unloading of the conditioned cocoons when conditioning is completed.

As regards the air heating equipment, it is of simple design. A masonry oven or furnace is built with a metallic cylinder passing through it. This cylinder is provided with a series of baffles internally to slow down the passage of air through it so as to facilitate proper heating of the air blown through it. One end of the cylinder leads to the lowest compartment of the cocoon chamber and the other end is connected to the blower.

The blower is massively constructed and generally provided with an electric motor. Air current through the air heater and cocoon chamber is regulated by the speed of the blower fan providing a cone or step-pulley for the blower.

If the cocoon conditioning plant is required for conditioning very large quantities of cocoons at a time, a battery or series of such independent vertical chambers are provided making suitable arrangements for hot air supply by adjustments in dimensions of the air heater and in the speed of blower.

Operation

Fresh cocoons are filled to about 2/3 capacity in the top–most chamber. After about three hours of exposure of these cocoons to hot air at 50°C supplied from the air heater, the wire mesh sliding door is pulled out and the cocoons dropped to the lower chamber where the temperature is 70°C. After three hours exposure the cocoons are again dropped into the third where the temperature is 75–80°C. Again after three hours, the cocoons are dropped into the fourth chamber where the temperature is between 80–90°C. In this fourth chamber the drying is completed in three hours. The dried cocoons are drawn out of the fourth chamber by opening the side door provided for the purpose. Thus the fresh cocoons loaded into the top chamber pass through the three chambers at different temperatures at regular intervals to be finally treated at maximum heat in the fourth and final chamber before discharging. This process, therefore, requires a total of twelve hours for complete desiccation. The process of cocoon conditioning is kept continuous by regular feeding of fresh cocoons in the top–most chamber. The cocoons at the time of withdrawal from the conditioning chamber after full drying are at a temperature of 90°C and therefore the cocoons require to be aired and cooled before storing in bags.

In this system of conditioning, the cocoons are kept moving in the direction opposite to the current of hot air until the drying is complete. Hence the cocoons are under gradual desiccation at increasing temperatures of hot air and their complete desiccation occurs in the hottest zone of the chamber. The design of the conditioning chamber and the mechanics of operation enables obtaining continuous drying operations without waste of time between discharge of cocoons and loading of fresh cocoons.

The hot air conditioning plants in use at present in different countries have been evolved from the older types of equipment as a result of experience and careful experiment. The basic requirements of a hot air conditioner are: (1) a chamber for keeping the fresh cocoons to be dried, (2) a fan or blower to supply a steady current of air to pass through the different layers of cocoons and carry off the products of desiccation during the drying process, (3) a heating equipment, either an oven for burning fuel or an electrically heated oven, for heating the air driven by the fan to the required temperature before the air passes into the chamber, have, however, been retained though each part of the equipment has been developed in design and construction to give the maximum required efficiency. Precise thermometric regulation of the temperature in all parts of the chamber is essential. Arrangements are also made for reading the temperature in any part of the chamber without having to open the chamber door.

Ventilation

The cocoon chamber is provided with adequate ventilation for rapid removal of the products of desiccation, which mainly consist of moisture and volatile gasesof which ammonia is the most important. Defective or insufficient ventilation causes the moisture or hot vapours coming out of the cocoon to condense in the drying chamber and acquire a strong alkaline reaction by the ammonia liberated by the pupae. When such water–drops fall on the cocoons kept in the chamber, the defect of spotting occurs on the shell. The filament in the spotted area gets damaged due to the alkalinity, and the reelability of the cocoon is spoilt. Hence complete and prompt exhaustion of the products of desiccation are quite essential.

A cocoon conditioning plant having the above essential features serves the following purposes:

(1) **Complete dessication:** The pupae must become quite dry and the cocoon weight should be reduced to about 1/3 of the original weight.

(2) **Partial desiccation:** By limiting the loss in weight to about 40 per cent of the fresh cocoon weight, it should be possible to increase the turnover of cocoon drying to nearly two fold in the same time.

(3) **Limiting the loss:** Similarly further limiting of loss in weight to only 20 per cent, the turnover can be stepped up to four times as compared to complete desiccation.

If the heat treatment aims at only killing the chrysalis, the turnover can be increased further to seven to eight times that of complete desiccation.

This adaptability of the conditioning chamber is of great advantage as it enables handling of not only small quantities of cocoons but also very large quantities of fresh cocoons received in the reeling factory. When the quantity of cocoons received is small, the cocoons can be fully conditioned and stored. On the other hand, when very large quantities of cocoons are received, the fresh cocoons can be taken in convenient batches and only partially conditioned in a short time and stored till all the cocoons are similarly treated. Once the risk of moth emergence is eliminated the partially conditioned cocoons can be re-cycled for completing the drying process.

In actual operation the modern conditioning equipment provides for the following:

(1) **Continuous operation:** This eliminates wastage of time between the discharging of conditioned cocoons from the chamber and recharging the same with fresh cocoons. Avoidance of a time lag between these two operations is of great advantage when very large quantities of cocoons have to be handled within a short time and in places where labour is scarce and costly.

(2) **The movement of the cocoon:** The movement of the cocoon in the chamber should be continuous and always in the direction opposite to the current of hot air being blown into the chamber. The advantage is that the cocoons are dried progressively in proportion to the increase in temperature, thus achieving complete desiccation in the zone where temperature is highest in the chamber. This technique of drying the cocoons is claimed to be very useful by European technicians who believe that cocoons can sustain without harm higher temperature with the progressive drying of the pupa. This view, however, is not shared by Japanese technicians.

According to Japanese opinion, the cocoon should be exposed to high temperatures initially for the purpose of killing the pupae and later subjected to progressively lower temperatures for gradual drying of the dead puape. Since silk protein is sensitive to the action of heat, the fresh cocoons should be subjected to high temperatures directly so that the heat energy is immediately absorbed by the juicy contents of the pupae, leaving the shell unaffected. With the increase in the rate of evaporation of moisture from the pupa, there is a corresponding increase in the chamber temperature which helps to maintain an even balance between the outside and inside cocoon temperature leaving little or no room for the action of heat on the cocoon shell.

A large number of factors are involved in the proper drying of cocoons that enable a high percentage of reelability to be obtained and as a consequence high grade raw silk. These are: the racial characters, the seasonal variations, shell ratio, quantity of cocoons to be handled at a time, the moisture contents, the speed of air fed into the chamber, rate of evaporation of moisture from the pupae, the temperature and humidity conditions inside the chamber, duration of drying, etc. By a series of experiments over a period of years, Japanese scientists have arrived at the following conclusions:

Mulberry cocoons should reach a drying ratio of 38.2 per cent if the shell ratio is 19.5 per cent and the dry weight of pupa is 23.5 per cent as per the following empirical formula:

$$D = (0.8944 - 0.0112\,X)\,Y + 1.12X$$

where D = drying ratio
X = dry weight of pupae
Y = cocoon shell ratio

There are several types of conditioning chambers differing in design and constructional details but all aim at attaining the objectives of an ideal conditioning plant. A few of the popular types are described below:

Pelligrino open type

This consists of a long rectangular chamber of masonry divided internally into two long horizontal chambers containing a number of steam pipes for radiating heat. Helped by ventilators the hot air passes into a passage provided between the two rows of cocoon boxes or cases placed in the upper chamber. If steam is not used, hot air from a separate air heating equipment is led directly into the passage. The passage has a number of holes one against each cocoon box on either side through which hot air passes into the small chambers under the cocoon boxes. The shutters of the holes are so constructed that they are automatically closed or opened when the boxes are raised or lowered respectively.

The cocoon boxes are made of wood and held in an iron frame, they are in fact deep trays. At the upper end of one side they are hinged on thin but strong beams, one beam between two boxes. The box fits so snugly into the chamber under them that no heat supplied from the passage escapes from the sides. All the heat supplied is utilised for drying the cocoons in the box. The boxes are provided with handles on either side by means of which they can be turned on their hinges.

The fresh cocoons are loaded in the cocoon boxes and are allowed to remain in one position for four hours and after that their position is changed every hour in such a manner that the cocoons of one box are put into another and so on. It does not require much labour, because the box has only to be turned over the hinges to empty the cocoons into the next box. The temperature maintained is about 80°C and the capacity of the conditioning plant is about 1250 kg in twelve hours, or about 2500 kg in twenty four hours. There are different models of the conditioning chamber with different capacities for conditioning. In the several models, the constructional details are the same, only the number of cocoon boxes are more, and aligned in two parallel rows instead of one row only.

The closed type of conditioner is similar in construction to the open type but instead of keeping the boxes open at the top, they are closed. Hence it is called the closed type. Each chamber has an opening through which the fresh cocoons are put into the chamber. Hot air radiating from steam pipes in the lower chamber goes into passage on the side of the upper chamber from which it goes into the cocoon boxes through small apertures. The change in the position of the cocoons is obtained by taking them out from the doors in front of the chambers after every six hours and putting them back into the upper partition of the box from the opening above. The chambers or boxes are inter-connected by means of openings in the side walls which can be opened or closed from outise depending upon whether it is desired to pass on or close the heat from one chamber to another. This type of conditioning plant generally has six chambers for cocoon drying and has a capacity for conditioning 1500–1800 kg of cocoons in 24 hours.

The main defect with this type is that the ventillation is neither adequate nor sufficient to exhaust the products of desiccation, and secondly the operation involves too much labour for frequent loading and unloading of cocoons. These shortcomings of the conditioning plant appear to have made this type less popular than the open type.

Tamburo-Girato

This consists of a pentagonal or hexagonal wire netting chamber built round a large pipe. It has at one end a mechanism of large cog wheels to enable the chamber to be rotated. Though it has a rotary motion (Fig 10) the circle is not completed, the chamber mading only a to and fro motion. The cocoons are put in this chamber and hot air supplied through pipes. The heating of the air is done either by steam or by furnace heat. The air is generally heated to 80°C. This type of conditioner can condition about 1200–1300 kg in 12 hours. The advantage of this type is said to be that the rotary motion facilitates uniform drying of the cocoons and involves less labour as the rotary movement is effected mechanically.

In all types of conditioning chambers so far described it is seen that the techique employed is to commence the drying process at comparatively low temperatures and gradually increase the temperature of hot air as the drying of the cocoons progresses. The final drying or complete drying is achieved at the highest temperature in the chamber.

In another technique popularly followed in Japan the fresh cocoons are exposed initially to high temperature for killing the pupae within a short time and desiccation is continued over a longer period at low temperatures. The cocoon conditioning is done in such a manner that the cocoons discharged from the conditioning chamber will be practically at room temperature. These techniques are practised in different countries. Whatever the differences in technique and their effects on the reelability of cocoons or the quality of the raw silk, the obvious advantage of the Japanese technique seems to be that as the cocoons discharged from the conditioning chamber are at more or less room temperature, they can at once be directly packed in bags, without spreading for cooling as with the other method. This is important especially where labour is scarce or costly.

In Japan the fresh cocoons are first subjected to a very high temperature of about 95°C and the temperature is gradually reduced as drying of the cocoons progressess, and finally reduced to 50 or 55°C, when the cocoons leave the chamber about six to eight hours after charging. High temperature is maintained only for two to three hours and later the cocoons are allowed to cool off gradually and at the same time get slowly dried. As the temperature of the cocoon at the discharging end is only 50–55°C, it is possible to bag the cocoons continuously with conditioning process thus eliminating unnecessary space, time and labour required for spreading and cooling the cocoons.

The cocoon chamber is a room where enough cocoons destined for drying are accommodated. There are several types of cocoon chambers differing from each other in shape depending upon the mode of placement of cocoons. The heating equipment generally consists of a furnace and heating pipes, or heaters utilizing steam heat or electric heat etc., but steam heat is mostly used.

Ventillation equipment or an air blower either leads the outer air into a pre-heated room or directly into the heating equipment, and thus gets heated up initially. The hot air is then led into the cocoon storage room, where drying takes place and the moisture from the pupal body and the cocoon shell are eliminated through accelerated evaporation. Later the hot air laden with moisture is allowed to escape through dampers by natural draught or by mechanical means.

The Doshitsu type drying apparatus was developed from the fire heat drying machinery where the fire is produced by the direct combustion of fire wood or coal. However, at present on account of the fire hazards it has been replaced with steam heat produced from indirect combustion. Further, there is a cocoon storing chamber which is made into separate shelves, (Hayashi model, Shigahara model etc.). In later models, the partitions are removed and all cocoon shelves are moved inside the cocoon chamber in a tunnel (Obikawa Nitsuke style). A further improvement nowadays is that the cocoons are loaded on endless conveyer belts and the cocoons are subjected to heat while traversing through the temperature-regulated hot chambers for dry stifling. Here properly dried cocoons are automatically led into the cocoon storage bag.

In order to achieve uniform drying of cocoons and also to eliminate stagnant pockets of hot gases or vapours, the cocoon rack is revolved (Nakahara model), or moved up and down (sumito style) or moved forward (Obikawa Mitsuko model), or these methods are combined. Nowadays in most of the cases the cocoons get only minimum movements. In the Sohutsu model there is an exhaust pipe and formal inlet. The hot air follows a running course and fans are employed in order to check stagnation of moist hot air. In this way uniform temperature is achieved. Recently in each of the above mentioned types many improvements have been affected to secure better reeling results. However, the endless belt type, fixed–movement model and automatic model (Kimamura model, Tahata model, Dalwa model etc.) are some of the popular cocoon drying machines in use at present and the most popular among them is the Yamato Dryer of six stages and eight stages. There are also small types of dryers to meet the needs of small establishments or for experimental purposes.

Generally in the Yamato dryer, there are eight conveyor platforms — one in each chamber — arranged one below the other in zig–zag fashion (Fig. 11). Such platforms are usually 18 m long and in operation move at a speed of 18 to 24 m per hour. Thus the total length traversed by the cocoons in the process of conditioning is 144 m and the time taken for full conditioning is about six to eigth hours depending upon the speed of the conveyor platform or belts. In order to make the movement of cocoons from one platform to another automatic and continuous, the movement of the conveyor belts are regulated in such a way that each conveyor moves in the direction opposite to the conveyor next to it in the lower chamber. There are special arrangements to control the air current and to diffuse the hot air in the several layers of the cocoons in the conveyor belt for ensuring uniform and efficient drying of the cocoons. In a cocoon drying chamber having 8000 kg capacity the following indicates the process of conditioning. The first five chambers have temperatures in the following descending order:

1st — 93°C - 95°C
2nd — 84°C - 85°C
3rd — 80°C - 82°C
4th — 77°C - 80°C
5th — 74°C - 75°C

These five shelves are the shelves in which drying occurs progressively. In the succeeding three shelves the temperature is as follows:

6th — 65°C
7th — 60°C
8th — 54°C

And here the gradual cooling of the cocoons occurs along with drying of the remaining moisture in the cocoons. The total time taken for the whole process from charge to discharge is eight hours. As most of the operations are done mechanically, two or three operators can easily look after the drying and bagging operations. The conditioned cocoons are automatically packed in large moisture and insect proof paper bags with double covering.

What makes the conveyor system successful and efficient in the sericulturally progressive countries is firstly that the cocoons produced are hard and more or less uniform in size and shape, and secondly that the surface of the cocoons are clean and free from floss. The former characteristics enable the cocoons to pass through the small openings between the moving platforms or conveyors and the fixed or stationary edges, without the cocoons getting flattened or damaged, while the less flossy quality helps the cocoons to remain loose and independent and fall off at required places without sticking to the conveyor or to any other projections in the chamber. Further the clean or floss free cocoons do not lump or club together and abstract uniform drying.

(d) Other Methods

Many methods other than steam and hot air have also been tried for killing the pupae. They are briefly indicated below:

Use of infra red rays

The qualityof silk is said to be well preserved if the cocoons are not exposed to high and prolonged temperature which renders sericin hard and consequently affect the reelability. Accordingly the use of infra red rays has been attempted. Initially the cocoons are dried partially to reach 60% dry wt. and later by exposure to low temperature it is allowed to reach the optimum drying ratio of 40% of green weight. However,the utility of this method is yet to be established on account of the high cost involved and marginal or negligible improvement in the reelability of the cocoons.

One Step drying Cellar Method

This method is to dry the cocoons in a specially built cellar or chamber with a platform inside about 30 cm from the ground level. A current of hot air at uniformly low temperature of 70°C is fed from above through specially designed ducts for a longer period. The fresh cocoons are spread in a layer about 7.5 or 10 cm deep and at regular intervals of two or three hours, fresh lots of cocoons are carefully spread to a thickness of 7.5 to 10 cm over the earlier lot. This goes on for a certain number of days continuously till the cocoons accumulate to sufficient thickness i.e. to the capacity for which the chamber has been designed. At this stage the bottom–most layer is brought up to the top and over this a fresh lot is again spread to a thickness of 7.5 or 10 cm. This procedure is continued until the cocoons in all the layers are thoroughly dried. This system of conditioning is claimed to be very economical because both conditioning and storing are done in the same chamber.

Cold air killing

In this method,pupae are stifled completely by the use of cold air at –10°C for 6 hours, and at –12°C for 4 hours. However maintenance of temperatures below freezing point requires heavy investment in installation of cold storage machinery as compared to the utilization of high temperature. Further, the cold storage plant will have to remain idle for long spells which would greatly add to the cost of stifling, and this method does not confer any extra benefit in good reeling.

Radio wave killing

If a high frequency impulse of 3–10 m wave length is passed through the cocoon, the pupa is killed within 2–5 minutes. In this method, the heat impings quickly on the body of the pupa on account of its higher moisture content and consequently there is immediate absorption of radiated energy. Moreover, the temperature rises to 65°C immediately but it does not increase beyond this point for some time. Compared to the above stifling methods, this achieves stifling at a lower temperature and in a shorter time. Further, there is very little effect of the temperature on the cocoon shell fibre. However, this method is yet to be applied on a commercial scale.

Poisonous gases

Various kinds of gases have been tried, such as sulphur dioxide, sulphuretted hydrogen and liquids such as carbon disulphide, chloropicrin, etc. Sulphur dioxide had to be abandoned because it damaged the silk. Carbon disulphide and chloropicrin are unsuitable because of their poisonous effects or inflammable nature. It is reported that at times of heavy arrivals of cocoons, methyl bromide fumigation is resorted to in the USSR without any apparent damage to cocoon quality.

(e) Storage of Cocoons

Storage of cocoons is an important problem especially when the stifled cocoons have to be stored for a very long period as in the case of univoltine areas, or when the seasonal conditions are unfavourable. Complete dessication of cocoons is a fairly satisfactory solution to the problem but even fully desiccated cocoons are liable to mould damage if the storage room is not kept dry. The other source of damage to cocoons in storage comes from the beetle pest, *Dermestes lardarius* (specially common in Italy). This beetle feeds on the fat contents of the pupae and to do so it cuts the silk shell and damages the cocoons. The beetle is attracted to the cocoon by the smell of the putrifying pupa as in the case of stained cocoons.

Preventive measures against this pest are more efficacious than curative ones. The primary care to be taken is to pickout all spotted and stained cocoons and throw them out as far away as possible from the healthy cocoons. Similarly care must be taken to see that waste cocoons and silk are stored as far away as possible from the cocoon stores. The walls and ceilings should be periodically disinfected. If insects are found in a package of cocoons all the cocoons in the container should be passed through dry hot air at 60–70°C for some time, till all the insects are killed.

Damage due to moulds

Mould develops when the cocoon store becomes damp and humid and when the cocoons are not fully dry as in the case of partial conditioning or steaming. Hence it is of utmost importance to prevent such conditions by taking the following precautions:

(1) Complete dessication of cocoons before storing should be ensured.

(2) All care should be taken to see that the relative humidity in the store room does not rise above 70%.

(3) The store room must have good ventilation.

(4) Cocoons should be given regular and frequent turnings during the period of storage and on no account should they be allowed to become damp. When fumigants are used care should be taken to keep the doors and windows open until all the traces of fumigants are removed.

(f) Sorting of Cocoons

Although the rearers of silkworms sort out the defective cocoons as well as the double cocoons before taking the cocoon produce to the market, there may still be a small percentage of defective cocoons which would have escaped preliminary sorting. It is also possible that some of the cocoons become defective when they are subsequently handled in the process of transporting, stifling, storing etc. Hence the cocoons require a second sorting to ensure uniform good quality cocoons for reeling. The type of defectives generally encountered in the second sorting are double cocoons, crushed and stained cocoons, cocoons with flimsy shell, malformed cocoons, fluffy cocoons and insect-damaged cocoons. These may be found only in very small quantities but even then they should be removed and rejected for production of high grade raw silk.

The cocoons are spread out on tables with low partitions and the sorters sit around the tables and pick out the defective and double cocoons separately. The double cocoons are later used for reeling dupion silk. The sorting room is generally located close to the cocoon stores and is provided with good ventilation and lighting.

In many filatures the cocoon stores are invariable provided with spacious open verandahs which are used for cocoon sorting operations. In Indian filatures, instead of using tables with low partitions, convenient sized bamboo trays or mats are used for keeping the cocoons for sorting. Rejections are placed in separate containers.

The disadvantage in the methods described above is that they do not detect defects that may be inside the cocoon shell, and such cocoons pass on to the lot of reeling cocoons. Only the obviously defective cocoons are rejected. This system of sorting, therefore, does not commend itself to modern techniques of reeling which aim at producing predetermined qualities of raw silk.

In Japan, the sorters detect even internally damaged cocoons and eliminate them by passing the cocoons over ground–glass plates illuminated from below. These glass plates generally measure about 38 x 38 cm square and are fitted in cut outs of equal size in a lamp–blacked table top or moving platform. A fluorescent light or sometimes even an ordinary 60 watt frost lamp placed in a suitable position under the platform provides the required illumination from below. When defective cocoons containing decomposed pupa and those with the inside discoloured pass over the glass plate they are easily detected. Similarly cocoons not having uniform thickness or compactness of shell are also easily detected. This method of sorting not only enables thorough sorting but is also economical, as sorting work is made easier for the workers. This method is popular in Russia. As regards the feeding or supply of cocoons to the sorting table or platform, it is done through hoppers placed above the sorting tables or moving platforms.

In smaller establishments where such elaborate arrangements are not made for economic reasons, the sorting tables are arranged close to windows. At a suitable place between the tables and the windows a reflecting mirror will be provided on the floor by means of which light from the window can be directed to the lower side of the ground–glass fitted in the sorting table. Someties to ensure better and more uniform light, the windows are provided with specially designed enclosures on the outside, having open top and the inner walls suitably painted to reflect as much light as possible.

Deflossing

This is an important and necessary operation especially when the cocoons have to pass subsequently through the several automatic mechanical processes such as cocoon riddling, boiling, collective brushing and automatic reeling. If the floss covering of the cocoons is not removed,it obstructs easy flow of cocoons in the automatic mechanical processes and results in slowing down the operations and increasing wastage of material, labour and time. Hence superficial floss must be removed soon after sorting. Deflossing of cocoons is generally done prior to the reeling operations as it serves in the earlier stage as a protective covering for the well laid reelable layer of the cocoon.

In the multivoltine areas where the cocoons are generally flossy and of medium firmness in build, deflossing is done by the sorters themselves by peeling the floss from the cocoon with the fingers. This method is no doubt laborious as each cocoon has to be taken individually for deflossing (Fig. 12) but the obvious advantage is that as each cocoon is individually deflossed only the required quantity of floss is removed from each cocoon. The disadvantage of this method is that it consumes too much time and labour.

In certain areas where univoltine cocoons are produced and the cocoons are naturally of firm build and have less floss, deflossing is done by using simple appliances. These consist of a rough–surfaced iron rod about 60–65 cm long and one cm thick. One end of this rod is bent into the shape of a short handle. The workers sit round a heap of cocoons and attend to deflossing. The handle end of the rod is held loosely and skilfully in the toes of the sorter's foot and the long end of the rod is carefully thrust a little below the surface layers of the cocoons heap. When the handle is turned briskly, the iron rod collects round itself the floss. The place of operation is shifted to different parts of the heap and the heap of cocoons itself is given periodic turnings to ensure uniform deflossing.

In sericulturally advanced countries, a simple hand operated deflossing machine is used when the quantity of cocoons to be handled is moderately large. It consists of a sloping wooden board having slightly raised sides on which are transversely fitted a number of closely arranged iron rods having rough surfaces. They are interconnected so that they can be turned by operating a handle placed at one end. The cocoons fed at the upper end of the inclined plane are slowly moved down the top surface of the iron rods and the iron rods are kept constantly turning in the direction opposite to the slowly descending cocoons. The projecting outer threads of the cocoons are caught by the rough surface of the revolving iron rods and the floss is stripped. This floss remover is not, however, suitable for ococoons which have too much floss and shells which are not robust and firm. Such weak cocoons flatten and obstruct operation.

Cocoon Riddling

In this operation the cocoons are separated according to their sizes. The deflossed cocoons are passed on to the riddling appliances which automatically separate the cocoons into large, medium and small sizes and collects them in separate containers. This is an important operation prior to reeling specially in areas where odd sizes of cocoons are produced since only uniform size cocoons offer scope for production of high grade silk.

There are several appliances used for riddling ranging from simple sieves to specially designed sensitive mechanisms.

In Italy, simple equipment consisting of two rectangular shelves with slightly raised edges made of strips of wood or metal with spaces between them is used. These shelves are placed one below the other and they slope in opposite directions (Fig. 13). Cocoons are fed at the top through a hopper. A simple cam placed below the shelves give a shaking movement and spreads the cocoons on the shelves. Due to the different size spacings in the two shelves, cocoons are automatically separated according to their size. They are collected in separate containers placed at appropriate places.

There are also appliances which combine the operations of deflossing and riddling. They consist of two distinct but connected parts. The first part deflosses the cocoons as they pass over suitably placed deflossing rollers at the end of inclined boards. The second part consist of an open horizontal cylinder made of iron bars so spaced that small cocoons fall through in the first section and medium sized ones in the second section, while large cocoons pass right through. The interior of the cylinder is provided with a spiralling baffle for moving the cocoons forward when the cylinder is rotated.

Cocoon mixing

In some modern filatures which aim at producing certain special qualities of raw silk, the three varieties of cocoons graded in the riddling machine are actually mixed in required proportions. This is called cocoon mixing or blending and is done to ensure speed and uniformity of reeling as well as to obtain the desired effect in raw silk. This sort of blending of cocoons has been found to be quite essential for ensuring a high degree of efficiency of the automatic reeling machines. However, with the advent of the denier control mechanism, cocoon mixing appears to have lost much of its importance.

Chapter 5

COCOON BOILING & BRUSHING

The product of the reeling operation is called Grege or raw silk. The raw silk for commercial use should have a minimum size of 14 deniers which usually requires assembling together of the filaments from five or more cocoons depending upon the denier size of the cocoon filaments or baves being unwound. As the bave windings in the cocoon are held fast by the natural gum sericin, it is necesssary to soften the gum by putting the cocoon in hot water before unwinding the bave. The process of softening is popularly known as cooking or boiling. The processing of softening of the gum by soaking in hot water also serves, on drying again, to cement the assembled filaments into a twistless but firm and industrially usable thread. It also helps in separating easily by a process of brushing, the entangled floss layer of the cocoon from the true end of the reelable filament making up the compact shell. It is relevant here to know the nature of sericin and its characteristics for proper understanding of the process of cooking and to analyse the factors that govern the unwinding of the filament from the cocoon. In this connection it is of primary importance to know the sericin content, the nature of the sericin and its reaction to heat,water, alkali and acid. Japanese scientists have carried out intensive research on silk protein during the last 40 years after the Second American–Japanese Technical Conference on Raw Silk Classification held in Yokahama when the defects in raw silk were pointed out by the American consumers.

(i) Chief Properties of Silk

The important findings on chemical properties of the mulberry silk and the protein chemistry of the silk fibre can be summarised as follows:

(1) Silk fibroin is comparatively stable against heat. If it is heated to 100°C it does not show any change except for loss of moisture and when cooled, it regains the moisture. If it is heated for several days at 100°C, it becomes slightly coloured. At 130°C decomposition begins and at 170° decomposition becomes quite rapid and it burns with an unpleasant smell.

(2) Concentrated hydrochloric and sulphuric acids dissolve a larger amount of silk than solvent acids.

(3) When silk is soaked in formic acid (90 per cent) at room temperature it swells and shrinks, but it regains its original length if, after being treated for 2–3 minutes, it is washed with water and stretched.

(4) The action of acetic acid is practially nil at room temperature, but the waxy material and a small amount of soluble protein are dissolved in glacial acetic acid. When silk is treated with acetic anhydride, the free amino radical in silk is acetylated. Dichloracetic and trifluoracetic acids dissolve silk very readily.

(5) When fibroin is soaked in 0.1N sodium hydroxide solution at 70°C, it dissolves at a constant rate, 50% of it after 20 hours. When silk is boiled with 0.1N sodium hydroxide, it evolves ammonia to the extent of about 9 per cent of the total nitrogen in fibroin. This value corresponds to the amount of nitrogen of serine residue in fibroin.

(6) Ammonia also decomposes fibroin gradually and when fibroin is boiled with 0.5 per cent ammonia water it decreases in strength and elongation with increase of time of treatment.

(7) Halogens combine chemically with silk fibre and on being cooled with ice, in the solution of chlorine (N/50) or bromine (N/50) its absorption proceeds rapidly inthe first thirty minutes and then slows down.

(8) Iodine is not absorbed so fast as chlorine or bromine but it is absorbed gradually when treated at room temperature for a long time.

(9) Oxidizing agents react destructively with the silk fibre.

(10) White silk changes colour to yellow gradually and becomes brittle by exposure to ultra-violet light. At the same time, silk also changes its chemical property. In other words, silk begins to lose xanthoproteic reaction to be coloured by indol re-agent of Ehrlich and becomes difficult to be dissolved in the solution of cupricthylenediamine.

(ii) Classification of Sericin

It will be observed from the above that silk protein is very sensitive to the action of heat, water, alkali and acid. While sericin is to be loosened to facilitate easy unwinding, it is also to be preserved as much as possible to facilitate proper agglutination of filaments in thread forming.

In 1865, Cramer separated an easily soluble protein from mulberry silk and named it sericin. Later H.H. Mosher, in American Dyeing Report published in 1932, classified sericin as sericin A and sericin B, while Kaneko and Inoue also classified the sericin identically in 1943. Oku in his book on sericin chemistry classified sericin into A sericin and B sericin. However, it was Shimizu who later proved, from a study using X-ray analysis, the crystalline structure of sericin to be as follows:

Sericin I, which is present in the outer layer of cocoon fibre and readily soluble, is present in an amorphous state, sericin II which is present in the middle layer, contains a certain part of crystal region and sericin III, which is present in the inner layer, has a certain crystal structure which is different from that of sericin II. When sericin is swelled, dissolved, dried and solidified, either sericin crystallizes or its solubility is reduced considerably. Sericin III contains a large amount of waxy material and its reflection appears in the X-ray diagram.

Amino Acids

Kirimura determined by a microbiological method eighteen kinds of amino acids in sericin, sericin in cocoon and native sericin in the cocoon gland. The analytical results for sericin obtained so far are shown below:

Amino acid composition of sericin

(Values are given as gm of amino acid per 100 gm of protein)

Amino acid	I	II	III	IV	Amino acid	I	II	III	IV
Glycine	1.10	–	4.1	8.8	Glutamic acid	2.25	1.91	2.9	10.1
Alanine	10.10	–	11.9	4.0	Serine	11.25	–	13.5	30.1
Leucine	3.40	–	1.7	0.9	Threonine	–	–	–	8.5
Iso leucine	–	–	–	0.6	Phenylalanine	–	–	–	0.6
Valine	2.50	–	1.3	3.1	Tyrosine	3.50	3.77	5.2	4.9
Arginine	3.75	4.15	5.1	4.2	Proline	2.25	–	–	0.5
Histidine	1.00	2.75	1.1	1.4	Methionine	–	–	–	0.1
Lysine	1.90	0.89	1.2	5.6	Cysteine	–	–	–	0.33
Aspartic acid	3.40	10.43	13.8	16.8	Tryptophane	–	–	1.0	0.5

I: Abderhalden et al. (1932) II : I to 1952
III: Sasaki et al. (1951) IV Kirimura (1955)

Solubility of Sericin

The characteristic of sericin is that it contains a large amount of serine and threonine, aspartic acid and glutamic acid and comparatively large amounts of lysine and arginine; this contrasts remarkably with the composition of fibroin. It is considered that the chemical characteristics of the two proteins differ due to the differences in the amino acid composition.

Sericin of cocoon fibre is easily dissolved by hot water in the case of mulberry silkworm. Normally sericin in the outer layer is most readily soluble while that in the inner layer which is close to fibroin is difficult to be dissolved. When the temperature is raised and the duration is prolonged, the dissolution of sericin is complete, but the sericin molecule is also affected and its properties change.

Wetting and softening of sericin which binds the intricate windings of the bave in the cocoon is done by subjecting the cocoons to the action of hot water. Proper cooking of cocoons for making them easily reelable with minimum wastage of silken material is a skilled operation requiring a complete understanding of the nature of the cocoon and the construction of the shell. The cocoon shell is naturally water repellant and the bave is more firmly cemented and held fast towards the matrix of the compact shell than at the outer or inner most layers. As regards sericin, it is less soluble in innermost layers than in the middle or outer layers. In 1954 Murayama assessed the solubilities of sericin in different layers as shown in the table below:

Cocoon layers		Big		Small	
		Total Sericin	% of Solu-bility	Total Sericin	% of Solu-bility
Outside	1	36%	9.5%	32.5%	7.2%
	2	21%	5.7%	74.5%	5.3%
	3	20%	3.8%	21.5%	4.7%
	4	19%	3.2%	20.5%	4.2%
	5	21%	1.7%	19.0%	4.0%

These peculiar characterisitics of the cocoon create problems in cooking all the layers of the shell uniformly. This problem becomes even more serious when dealing with cocoons which have a high percentage of silk, thick shell and fine bave, or with the cocoons that have been kept too long in storage or that have hardened shells due to prolonged exposure to high temperature in the cocoon conditioning chamber. There are two systems of cooking for the two different systems of reeling namely, "Top Reeling" or "Floating System", and "Sunken System". For top reeling, cocoons are cooked only to the extent the silk shell becomes wet but is still impervious to water so that they float in water when the cooked cocoons are put into the reeling basin. On the other hand, in the sunken system of reeling, not only the shell is cooked but in the process, the cocoon also gets filled with water inside to the extent of 97–98 per cent with the result that the cocoon becomes heavy and sinks in the reeling water. Top reeling is the old and conventional method whereas sunken reeling is a highly evolved technique devised for a special requirement of reeling.

(iii) Top Reeling

This method consists in cooking cocoons in ordinary open pans or vessels made of either earthenware or copper sheet with tinning inside the vessel (Fig. 15). Water is poured into the vessel and brought to boiling by application of direct heat from the fire below the basins. When the water begins to boil a handful of cocoons is put into the boiling water and kept immersed in water for a few minutes by using a perforated ladle. When the cocoons appear dull in colour and somewhat translucent, they feel soapy to the touch and the filaments easily come off when pulled. Cocoons in this condition are reckoned to be cooked.

This method of cooking though simple is technically defective. The outer layers of the cocoon in contact with hot water get cooked earlier than the middle or inner layers and if the cooking is continued till these layers also get properly cooked, the outer layer gets overcooked. This results in unnecessary dissolution or over-softening of the gum which causes the filament to come off in lump and also spoils the cohesion, lustre and cleanness of the reeled silk. Whereas, if the cocoons are removed for reeling soon after the outer layers are cooked, reeling becomes difficult when the middle and inner layers are reached. In either case wastage of silk increases. However, the defect of undercooking is overcome to some extent by keeping the reeling water at a high temperature, which adds to the cost of reeling besides causing other inconveniences to the reeler.

These defects of the common open-pan system of cooking are reduced to some extent in cooking basins provided with an automatic brushing device. In this method when the brush is lowered into the basin after the exterior of the cocoons is cooked, the brush fits snugly into the basin and keeps the cocoons well pressed down in the boiling water. This enables cooking to be continued under covered conditions when the brushing is in progress, thereby forcing the boiling water to inflitrate through the shell layers, and soften and loosen the layers evenly throughout.

As cooking and brushing are done in the same small basin containing a small quantity of water, the dirt and deleterious substances released from the cocoons make the water dirty with suspended impurities very soon, and the cooking operative has to keep draining the water regularly and adding fresh water to the basin. This naturally increases the consumption of water and steam for heating the water. Increased consumption of water and steam becomes a serious probelm where good reeling water and boiler fuel are scarce and costly.

Due to the smallness of the size of cooking basin only small quantities of cocoons can be cooked at a time with the result that the capacity of the basin to supply cooked cocoons for reeling becomes limited. This limitation has to be compensated by increasing the number of cooking units and employing more cooking operatives. All this involves considerable extra expenditure on equipment, labour and space.

Lastly, as cooking of cocoons even of the same batch is done in several basins in small quantities by different operatives, there are bound to be variations in the degree of cooking or in the quantity of waste removed from cocoons in the several basins. Thus, this type of cooking is not conducive to standardization of cooking and removal of waste, and therefore, offers no scope for standardization of the economics of cooking operation.

The only advantage of importance in this system is that the cooking operations are done in front of the reeler himself who can give timely instructions and guidance to the cooker regarding the degree of cooking required, and the cooker can easily manipulate the operations to suit the requirements of the reeler.

Three Pan Type

The deficiencies of the open pan type cooking have been overcome to a considerable extent by adopting a system of cooking totally different from that of the basin type, (Fig. 16) and it is popularly called "three pan type of cooking." This method consists of simple cooking equipment having three fairly large sized porcelain basins fitted in a row on a platform or table. The basins are provided with

water and steam connections. The accessory equipment consists of a long handled brass wire cage for holding the cocoons, a wiremesh disc of a special design with wooden handle for keeping the cocoons immersed in the basin, and long handled perforated ladles. An open shelf is provided as an integral part of the table in front of the basins for keeping the accessories. Towards the end of the table a platform for keeping the trough which receives the boiled cocoons is provided. In addition to these, the cooking unit is served by trolleys for carrying small wooden tubs with water for transporting the cooked cocoons from the cooking unit to the reeling basins.

The three large basins are filled with water and the temperature brought up to 90°C or 95°C in the first and last pans while the temperature in the mid pan is kept at 60°C–65°C. The water in the receiving trough and in the cocoon carrier basins is kept at 40°C–45°C. A required quantity of cocoons is taken and placed in the wire cage and after securely fastening the cage it is immersed in the first pan for about 60 seconds. In this pan air in the cocoon cavity is heated and expelled. The cocoon cage is briskly lifted out of this pan and immersed in the second pan containing water at 65°C for 30 or 40 seconds. Here the air inside the cocoons contracts and water from the basin is sucked in. Hot water permeates as a result of the first dip. In this process the cocoon shell layers are loosened and the hot water entering through the shell softens and swells the sericin layer and water partly fills the cocoon cavity. From the second pan the cocoons are discharged into the third pan having water at 90 or 95°C, and the cocoons are kept immersed by pressing down with the specially designed wire mesh disc. Sometimes the pan is also closed with a lid. In this basin the hot water at 90 or 95°C thoroughly soaks the cocoons and fills up the cavity to a considerable extent. A small quantity of sericin is also dissolved. The cocoons are kept immersed in this basin for one to two minutes depending on the quality of the cocoons used and the degree of cooking required.

From the third pan the cocoons are transferred using long handled perforated ladles to the cocoon–receiving trough for onward supply in small buckets to the reeling basins for brushing and reeling. The process is made continuous by having two or more sets of the accessories and charging the vacant basins with cages with freshly filled cocoons as quickly as possible. The advantages of this method are:

(i) Cocoon in sufficiently large quantities are cooked in a short time, and as the capacity of each unit is about 60 to 70 kg of cocoons per day, one unit can easily supply cocoons to ten or twelve multi–end reeling basins with one or two operatives attending to the cooking unit. Thus labour is saved to a considerable extent.

(ii) As the method involves permeation of water into the cocoon the intricate crossings at the different cocoon layers get swollen and loosened and thus improve the unwinding quality of the filament.

(iii) All the cocoons are subjected to the same treatment and for the same period and hence uniformity in cooking is obtained.

(iv) As brushing of cocoons is done separately the cooking water does not soon become turbid.

(v) As the cooking unit is situated away from the reeling basin and attended to by a separate skilled operator exclusively for the purpose, more efficient cooking becomes possible and the reelers can concentrate their attention on the all important and skilled work or reeling without any distraction.

The disadvantagesof both open–pan and three–pan cooking for float reeling are:

(i) Reeling has to be done at a higher temperature which tends to affect the palm and fingers of the reelers and thus impair their reeling efficiency.

(ii) Larger quantities of steam are required for heating the reeling water and water vapour from the reeling basin increases the humidity in the hall and decreases the visibility especially during the rainy and winter seasons. Increased steam requirements also add to the cost of reeling.

(iii) As cocoons are not brushed in the cooking basin except in the case where mechanical brushing is provided, brushing would have to be done by a separate set of operatives using separate equipment, or reelers themselves would have to brush the cocoons in a part of the reeling basin. The former would complicate the mechanism and design of the reeling basin besides increasing the workload on the reeler.

(iv) Further as cooking and reeling are separated, cost on equipment and supervisory staff and the additional space required would increase. However, the qualitative output would amply compensate the extra cost.

(iv) Sunken System of Reeling

This system is so called because the cocoons cooked by this method sink in the water at the time of reeling. Research on the problems of cocoon boiling and their effect on reeling has revealed that the raw silk reeled is greatly influenced by the technique adopted in boiling the cocoons and the conditions of the cocoons at the time of reeling. It is found that cocoons in a sunken condition in the reeling basin yield the silk bave more readily than when they float, thus adding to the ease and efficiency of reeling. Hence attempts were made to obtain the cooked cocoons in a condition which would make them sink in the reeling water. This could be done only by increasing the weight of the cocoons by expelling the air contained in the cocoon cavity and replacing it with water. In this process of filling the cocoons with water, the shell also gets uniformly cooked in all the layers. To achieve this, a special technique is adopted partly derived from the three-pan method of cooking.

One of the methods adopted is to cook the cocoons in a basin containing water at 83–93^{0}C and boil the cocoons under covered conditions. The cover is then removed after a short time and boiling continued for about one third the predetermined time for boiling. Then the cocoons are douched in a cold water spray. Thereafter boiling is again continued for some time under covered conditions. When the boiling has progressed for some time, the heat supply to the water is stopped and the cocoons are once more sprayed with cold water. Then the cocoons are transferred to wooden cocoon carrier tube of convenient size and containing water at 40–45^{0}C for the brushing and reeling units. Cocoons cooked in this method are filled to an extent of 97 per cent of the cavity and therefore sink in the reeling water. As the cocoons have been thoroughly boiled and their sericin softened uniformly in all the layers, there is no need to keep the reeling basin water at a very high temperature, as in the floating system. Tepid or lukewarm water is quite sufficient for the sunken system of reeling.

In all large scale modern reeling establishments using highly developed reeling machinery for large scale production of superior quality raw silk, the three-pan system has been replaced by the conveyor cooking machine or a central cocoon boiling machine.

This equipment consists of a sturdily built long rectangular wooden container (of best quality non-water absorbant cypress wood) firmly held in an iron frame. This container is sub-divided internally into six processing chambers and one open chamber for loading the cocoons. Each processing chamber has its own specifications of size and constructional design to suit its particular function, (Fig. 17). Each chamber is also provided with independent water and steam circuits to facilitate maintenance of proper temperature and steam pressure, thermometer and pressure gauges and inspection windows. The chambers containing water are also provided with overflow pipes for draining and maintaining a steady level of water. In some types of cooking machines even automatic devices are provided for obtaining the exact temperature and pressure in the several chambers.

The machine is internally equipped with an endless chain conveyor carrying on it a series of wire cages generally made of brass (as brass has no action on silk) for holding cocoons intended for cooking.

When the machine is in operation the conveyor slowly carries the cocoon cages through the several chambers of the machine. Generally a cone pulley is provided on the main drive shaft to enable adjustment of the speed of the conveyor. This is necessary because the time factor of each process in the several chambers depends upon the length of passage in the chamber and the speed of the conveyor moving through it. As the size of the chamber is fixed, adjustment in speed of the conveyor regulates the time factor for the particular process. As regards cocoon boiling capacity, it is different for different types.

In spite of the seemingly elaborate mechanism of the machine, it is quite simple to operate and needs only a 1 H.P. motor. Only two persons are required to operate it. The operatives however should be technicians and must know how to handle the various controls of the boiling machine. Carlessness in regulating the temperatures and pressures will result in destruction of the cocoons. Hence it is of the utmost importance to determine the temperature and pressure required for a particular lot of cocoons by actual pre-testing of the cocoons for quality, especially regarding percentage of silk, compactness of shell, size and shape. Best results are obtained only when the cocoons are quite uniform in these qualities. The conveyor method of cocoon boiling is a common feature in all modern reeling factories in sericulturally advanced countries. The six different processes or treatments to the cocoons passing through the six chambers of the machine are as follows:

First Chamber

This is called the "Dipping" or "Wetting" chamber. It contains water at 40°C to 42°C where the cocoons are treated for about 30 to 50 seconds. The surface layers of the cocoons which will be in direct contact with hot water swell slighly due to wetting.

Second Chamber

This is the steaming or steam blasting chamber. The wetted cocoons coming in from the first chamber are exposed to the action of steam at about 90°–95°C at proper steam pressure. The effect of this treatment is that the air inside the cocoon cavity is heated up to cause its expansion and partial replacement. As the hot dry steam is likely to make the sericin layers stiff and slightly less soluble, the optimum duration of treatment is limited to 60 seconds.

Third Chamber

This is the permeating or infiltration chamber and contains water at 40°–60°C. Due to the lower temperature, a partial condensation of the steam occurs in the cocoon cavity and the cocoon sucks in water thereby uniformly wetting all the layers of the silk in the shell, without dissolving the sericin. Treatment time is 30 seconds.

Fourth Chamber

This is the steam cooking chamber in which the cocoons from the third chamber are subjected to steam treatment for 118 to 120 seconds keeping the temperature and pressure at 95°C to 98°C and 0.33 kg per cm^2 respectively. This treatment causes the sericin to swell and soften the silk layers, and the steam to fill up the cocoon cavity.

Fifth Chamber

This is the cocoon boiling and adjusting chamber and is very important because it is in this chamber that the steam contents of the cocoon cavity is replaced by water by gradual condensation of steam in the cocoon obtained by gradual cooling of the water from 98° to 60°C. Accurate maintenance of the reducing temperature — gradient is most important because too sudden cooling causes the cocoon to collapse or buckle. Actual time for the operation depends upon the compactness and other qualities of the shell. Weaker cocoons naturally require a prolonged gradient in temperature adjustment, and therefore takes longer time.

Sixth Chamber

This is the finishing chamber containing water at 50°–60°C. In this chamber water easily enters and fills up whatever space is still left in the cocoon cavity leaving only about 3% or less of air space. Cocoons in this condition after 10 or 11 minutes are automatically discharged into a receiving trough containing hot water at 40°–50°C for transfer to the next process of brushing.

The cocoons discharged from the boiling machine are filled with water and therefore sink in reeling water during the reeling operations. Sometimes certain chemicals are also used in the infiltration chamber to enhance reelability. In that event the degree of boiling according to the quality of cocoons is adjusted. Generally the fibre swells and the surrounding area is loosened. The swelling or softening can be accelerated with the aid of swelling agents of the non–ionic or anionic type to improve the unwinding ratio of the filament. These agents are selected according to the hardness of the cocoon shell. Optimum dosages are arrived at after trials with the quality of cocoons available in different regions and seasons.

The main advantages of this method of cocoon boiling for the sunken system of reeling are:

(i) Degree of cooking is unformly achieved in all cocoons and in all layers.

(ii) reelability is improved and enables reeling of 40 to 50 ends by one reeler thus increasing the output per reeler.

(iii) Only nine to ten trained workers are required for supplying cooked cocoons to about 400 multi–end basins, whereas in the ordinary type a minimum of 200 cookers would be required. This economy in labour requirements is of special importance in countries where labour is scarce and costly.

(iv) The percentage of wastage is reduced and standardised.

(v) As reeling is done in tepid or lukewarm water, steam consumption for heating reeling water is considerably reduced and therefore, water and fuel economy is attained. Using less steam in the reeling hall reduces mill dampness and vapour formation in summer and winter. Reduced mill dampness considerably prevents occurrence of such defects as hard gum spots, ribbing and plastering defects and improves ventilation and visibility.

(vi) Low temperature of reeling water does not injure the fingers and palm of the reelers and, therefore, does not in any way impair their reeling efficiency.

(vii) Due to non dissolution of sericin and avoidance of over–softening of the sericn, coehesion of reeled silk is very good.

The modern concept of rational reeling is to unwind the filament at a slow speed to avoid excessive tension and to provide sufficient opportunity to maintain the requisite number of cocoons at each end. In other words, slow reeling over a number of ends ensures higher productivity and greater evenness and cleanness standards for the raw silk.

(v) Brushing

After the cocoons are cooked either for the floating system or the sunken system, the cocoons have to be brushed for removing the surface floss layer of cocoons. The floss layer of the cocoon is entangled and coarse and does not yield silk for reeling. Further it obstructs reeling of the clear bave and so its removal ensures high standards in raw silk. The floss layer is removed by a process known as brushing.

Generally speaking in preparing cocoons for the floating system of reeling, cooking of cocoons and brushing them for removal of floss from twin operations conducted in the same basin and by the same operative. The only system in which there is a departure from this practice is in the three–pan type of cooking, which also cooks them for the floating system of reeling only. In this type the cocoons are only boiled and passed on for brushing to the cocoon brushing section or with the aid of a brushing device provided at one end of the reeling basin, the reeler does the brushing of the cooked cocoons supplied to him. Generally when the cocoons are prepared for the sunken system of reeling, cooking is always separated from the brushing bath which may have a collective brushing device or a mere soft fibre automatic brush provided for the brushing part of the reeling basin. The popular methods and equipments used for brushing are described below:

(1) Stick

A single flexible, thin, soft stick is frequently used for removing the floss from boiled cocoons. The operative holds one end of the stick and with the other end carefully removes the floss from the cooked cocoons in the basin by dextrously working the stick in a series of figures of eight among the cocoons in the basin, (Fig. 18) in such a way that the stick comes lightly in contact with the surface of the cocoons and catches and draws off the flossy waste. When sufficient quantity of floss has been taken off the cocoons and wound round the end of the stick, it is lifted up from the cocoons and in the process draws up the baves from the floss layer attached to the lump of the waste on the stick. The stick is then removed and the operative takes hold of the lump and lowers it towards the cocoons, gathering in the process the released floss threads. Then holding the collected lump close to the cocoons, several side to side movements are given with the object of further loosening the small quantity of floss that would be still remaining on the cocoons. The lump of waste is then lifted up to about 25–30 cm above the cocoons and the released baves from the cocoons drawn up along with the lump waste are caught and separated from the waste at the point of contact of the baves and the lump of floss waste. The waste is kept aside for further cleaning and drying. The cocoons with their rleased reelable baves are transferred to the reeling basin in a perforated ladle taking care to twist the loose ends of the released baves.

Sometimes instead of a single piece of stick a prong made of two pieces of sticks or twigs is used. The operative gently taps the surface of the cocoons repeatdly with the prong in several parts of the cocoon group in the basin and everytime the prong is lifted, filaments from the floss layer are drawn up. These are gathered in the hand of the operative till sufficient quantity has been collected. Then in the manner already described above, the rest of the floss is removed.

The stick or prong method may be used successfully when handling multivoltine cocoons having much floss layer which easily gets caught by the prong. These methods are popularly used inthe Charka system and other older types of reeling in the cottage reeling sector. But the equipment is not suitable for hard–crusted univoltine cocoons with a thin layer of closely clinging floss. An important point for consideration in the use of the stick is that it should not be too roughly used, as otherwise the silk bave in the shell is likely to be damaged and the pupae in the shell ruptured. Also, as the stick does have enough catching surface a comparatively longer time is taken for brushing the cocoons and, the cocoons therefore have to remain for a prolonged period in very hot water which is detrimental to reelability. These deficiencies have been overcome fairly effectively by using soft, long–bristled brushes.

(2) Hand Brush

This brush is generally made of fairly thick and long fibres tied like a broom. The brush is made of fibre bristles which are thick and flexible and not too stiff. They are generally made from a strong vegetable fibre like Khus–Khus grass *(Vetiveria izanioides)* or sometimes from paddy straw. The brush is about 15–20 cm long and has a flat, circular brushing surface about 6–8 cm in diameter. The handle end is tied into a close pack (Fig. 19) to afford the brushing operative a good grip. The softened floss of the cooked cocoons in the basin is gently brushed by circular movements of the brush lightly touching the surface of

the cocoons. The brush is then lifted up and the floss waste removed in the manner described above. As the brushing surface of the hand brush is large with hundreds of bristles, brushing of floss is done quickly and more efficiently. Due to the flexibility of the bristles there is no risk of injuring the bave or rupturing the pupae.

In filature reeling machines, the cooking basins are invariably provided with mechanical brushing devices. Hand brushing has been completely replaced by mechanical brushing.

Mechanical Brushing

When the cocoons have been put into the cooking basin and ladled a few times with the object of boiling the cocoons, the automatic brush is lowered into the basin. Immediately the brush commences to make fairly brisk clockwise and anticlockwise rotary movements with three–quarters of a turn in each direction, alternately. After a definite number of rotary movements (generally 20 to 24) the brush is lifted out of the basin either by the cooking operative or automatically (Fig. 20). It is important that the required temperature of the water is obtained even before the brush is lowered. When the outer layer of the cocoon has thus been well brushed, it comes off easily drawing with it most of the reelable ends of the bave of all the cocoons.

The operative carefully collects the teased outer floss and draws off all the baves until they unwind cleanly from the cocoons without any of the floss layers still sticking to them. This process done in continuation with the brushing operation is called "clearing the bave." The cleaning of the bave is mostly done by the cooking operative but occasionally it is also done in a separate basin adjacent to the cooking basin, so that when the baves of the cooked cocoons are being cleared in this basin, a fresh lot can be put into the vacant cooking basin for boiling and brushing. Sometimes when superior cocoons are being reeled at high speed and supplies of cooked, brushed and prepared cocoons have to be brisk, the clearing of the bave is done in a specially designed oval basin by a separate operative. The brushed and prepared cocoons are transferred to the reeling basin either in a wooden tub or a perforated dipper or a ladle with the bave ends of the cocoons twisted and tied to the hook.

Precautions to be taken in this system of machine brushing are:

(i) Cocoons should be thoroughly well sorted and should be of uniform size and build.

(ii) Only one layer of cocoons should be on the surface of the water and the water level should be constant and maintained at such a level that all the cocoons in the basin touch the brush and are effectively brushed. In some machines, special arrangements are made for automatic maintenance of water level in the basin.

(iii) The steam supply should be stopped when the brush is lowered into the basin to avoid over–cooking of cocoons during brushing.

(iv) The brush should always be kept clean and free from clogging by silk waste and other extraneous matters released by cocoons.

(v) When unyielding cocoons are returned from the reeling basin they should not be cooked again with fresh cocoons but should be treated separately. In some machines separate basins are exclusively provided for this purpose.

A modified form of mechanical brushing is provided in the modern multi–end reeling basins. Where the brushing device is not provided for the cooking basin it is provided for each reeling basin itself. The reeling basin has a suitably designed compartment or chamber at one end exclusively for brushing the cocoons supplied from the cocoon boiling machine. As the technique adopted in the modern multi–end reeling machine is the sunken system of reeling, the cocoons sink in the cooking basin instead of floating. The brushing device is very similar to the previously described automatic brush but instead of being one large brush, it has a number of small brushes protecting from the main brush holder. Thus when

the brushing device is lowered for operation, the several brushes plunge into the basin with cocoons and each brush starts making rotary movements. Since the brushes dip into the group of cocoons and brush the cocoons surrounding them thoroughly, there is no need for the cocoons to be only in one layer. This arrangement enables the reeler himself to brush and prepare the cocoons.

Central Cocoon Brushing Machine

The latest trend in brushing devices is to have a specially designed brushing machine which does mass brushing of the cocoons cooked in the boiling machine. The device is very **ingenious** in construction and is calculated to standardise the brushing process and, therefore, standardise the percentage of waste removed, (Fig. 21). It also saves labour by making all operations of brushing mechanical and automatic. The brushing machine is electrically operated and consists of the following distinct but interrelated parts.

(i) Cocoon receiving trough

This trough is rectangular in shape and holds water a few centimetres deep. The temperature is maintained at about 40^0–50^0C. On one side there is an overflow drain covered by a sieve to let the excess water drain out. The exit for cocoons is at one corner of the trough. The exit passage is provided with a rotary, pronged lifter which continuously operates lifting a handful of cocoons at a time and putting them into the brushing part of the machine. The operative in attendance generally keeps disentangling the cocoons received in this trough from the cocoon boiling machine in order that the cocoons may easily move towards the exit heading to the brushing part of the machine.

(ii) The collective brushing sector

This sector is naturally the most important part of the whole machine. It consists of a shallow trough with a centrally placed revolving dome carrying a number of rotary brushing discs located towards the periphery and spaced at equal intervals. The speed of the dome is adjustable between 20 to 30 RPM. Each disc in turn carries twelve soft coir or fibre brushes held in revolving holders. Thus when the main dome revolves, the several brushes connected with the main dome are individually set revolving. The temperature of the water in the brushing trough is about 80^0–85^0C.

Cocoons from the main trough are fed into the circular path of the brushes and the brushes catch the cocoons, brush them and drag them forward. When the brushes reach a particular point in their circular movement the brush holder at that point gets lifted up by about 12–15 cm and automatically draws up the brushed fibres along with the brushes. A thick wire vibrator located on one side and close to the point where the brushes are lifted up, guides the teased fibres from the cocoons up an inclined saw–tooth chain elevator. This elevator gathers up the released fibres at the top point. The collected fibres along with the released fibres are gathered by the operative and guided to the discharge point of the brushing sector. The discharge point is provided with a hand–operated mechanism for discharging the brushed cocoons into carrier troughs placed immediately below the discharge points.

Those cocoons which have not been caught by the revolving brushes, move towards the deeper part of the brushing trough, where they are automatically lifted up and pushed forward again into the brushing sector. This enables the cocoons to keep circulating in the brushing sector until they are caught by the brushes and get brushed. A suitably placed metallic comb automatically cleans the brushes. The whole equipment is compact occupying an overall floor space of about 4 m^2. This type has a capacity to brush about 60 g of cooked cocoons per day. The whole unit is driven by an independent electric motor. As regards labour only one or two trained operatives are required.

From the description of the several processes the raw material passes through before it is actually used for reeling of raw silk, it is seen that an appreciable part of the silken material of the shell has been taken off as unsuitable for reeling purposes.

It is a conspicuous fact that in the continued attempts to reduce dependence on labour in the reeling industry, technology in reeling has advanced towards standardisation of production, wastage, quality of product and the cost of manufacture.

Chapter 6

REELING OPERATIONS

(i) Reeling

Raw silk having certain specifications is obtained by adopting any one of the two methods of reeling popularly known as (i) direct reeling method on standard reels and (ii) re-reeling method which includes preliminary reeling on small sized reels and transferring the reeled silk directly from the reels to standard sized reels on re-reeling machines.

The temperature of water in the reeling machines should be kept at optimum levels suited to the type of appliance used, nature of water and condition of the cocoons at the time of reeling to keep the reeling at high operational level. The cooked and brushed cocoons with their filaments cleared are put into the reeling basin and transferred to the reeler. The ends of the released clear baves are tied to a hook provided on the reel bench near the basin.

Formation of the reeling end

A required number of baves from as many cocoons according to the size of raw silk thread to be reeled are combined and passed upwards through the guide-eye of a threader, (Fig. 22) which is either a porcelain button or a jettebout (see below) with the object of primary grouping of the several baves drawn and combined to form the required composite thread. The group of baves emerging from the threader is then passed over a device consisting of two or three small wheels or pulleys so placed to intertwine the thread in a large number of spirals before it is finally passed through another guide eye of a distributor mechanism attached to the reel. This system of intertwinment is called croissure and plays an important part in the production of a good single thread with the component filaments firmly agglutinated. This operation is repeated at each threader provided for the reeling basin. Each place of thread production in the basin is called an end, and the group or cluster of cocoons from which the thread is formed at each end is called a rose or rosette, and the conical formation of the filaments from the rosette to the threader is referred to as balloon. Each reeling basin is provided for reeling several ends ranging from four to ten in the older types of reeling machines to twenty in the modern reeling machines.

Jettebout

The most important and skilled work of the reeler, apart from proper preparation of the cocoons, consists in attaching fresh filaments (Fig. 23 & 24) as required promptly to the silk thread under reeling in order to maintain regularity of size and continuity of thread. In the old type of reeling machines this was generally done by skilful slinging or casting of the loose end of the cleared bave of the cocoon on to the balloon of the end below the thread guide. The fresh filament became attached and drawn up by friction. Slinging or filament casting is laborious and taxing and the necessary skill and quickness are attained only after a considerable practice and training. Due to the difficult nature of the operation fluctuations in size are wide and frequent. Furthermore, any carlessness in taking the correct length of filament on the finger for casting causes several types of defects in the raw silk. "Casting" technique puts a limitation on the number of ends a reeler can manage because of the low rate of casting in manual operation. With the object of overcoming the deficiencies of this technique and to facilitate prompt attachment of filaments, the modern basins are provided with the device known as a jettebout.

The jettebout is said to have been originally invented in France by an American Engineer named Serrel. This mechanical gadget was later perfected and adopted universally in all modern reeling machines. The jettebout is intended and designed to combine the functions of the ordinary procelain

button thread guide and an automatic thread catcher. The mechanism of the jettebout is simple and ingenious. It consists essentially of two brass tubes, one outer and one inner. The inner tube is firmly fixed to the main jettebout frame and the outer tube revolved round it. The inner tube has a small bore through it with a small glass button or head firmly fixed at the top through which the thread passes. The lower end of the revolving outer tube has a circular disc with slanting cuts in it. In some types of simpler jettebouts, the lower end of the revolving outer tube is provided with short extending arms instead of the notched disc. There are different types of jettebout varying in constructional and mechanical details especially regarding the method of drive. While in some the jettebout is driven by a thread or spring wire passing over grooved wheels on the revolving outer tubes, there are other types driven by gear mechanisms.

When the drawn end of the released bave from the cocoon in the reeling trough is held between the fingers and brought in contact with the revolving disc, the stretched bave is caught by the fast revolving projecting arms or the sharp notches in the disc and the bave is pulled and cut. The cut end remains in the hand of the reeler while the other part of the bave falls on the fast moving balloon which is passing through the bore of the stationary inner tube of the jettebout. The speed of the jettebout is an important factor in determining the efficiency of the device. Due to friction the freshly dropped thread catches on to the balloon and gets drawn in to be grouped with the other filaments already being reeled. The jettebout has thus eliminated the old cumbersome and slow technique of hand slinging or casting of filament. With considerable improvement in the rate of casting with the aid of the jettebout, the reeler finds it easier to operate a greater number of ends in a basin. This results in increased production per reeler and it is estimated that under normal conditions of reeling the jettebout increases productivity of the basin to an extent of nearly 33 per cent.

Croissure

Croissure as already stated is a mechanism of intertwining or crossing of two threads by twisting the threads in a series of spirals during its passage from the threader to the reel. The primary effect of the croissure is to knead the group of filaments passing through the spirals to form a round, smooth and compact thread firmly cemented or agglutinated with an even coating of sericin. Firm cohesion of the component filaments is very important, as otherwise the loosely held baves get broken in the subsequent manufacturing processes and crease up to form an unsightly fuzz on the surface of the yarn or finished fabric. The other important effect of croissure is to squeeze out a large part of the water contained in the filament passing through it. This is necessary because the cocoon filaments coming out of the reeling bath are thoroughly soaked with water, having absorbed water in quantities equal to their own weight. If the excess water were not removed before the silk is wound on the reel it would give rise to occurrence of serious defects like hard gum spots. Thus croissure makes the thread cohesive and lustrous.

There are two types of croissure — Chambon and Tavellette. Of these Chambon is considered defective and has been replaced by Tavellette in modern filature reeling methods (Fig. 25). In the Chambon type the two groups of threads coming out of the thread guides of the reeling basin are intertwined over each other in a few spirals and the loose ends taken through the distribution guides and attached to the reel. The thread from the right passes to the left and vice–versa. This type of croissure, though given up in modern reeling, is still popular in hand–powered or foot–treadle reeling equipment used in house–hold reeling. Chambon is simple in technique of application and does not require elaborate devices on the reeling machines, but it suffers from serious drawbacks such as interdependence of threads drawn from separate ends for croissure effect, formation of double threads and the severe restriction imposed on the reeling ends.

The defects of the Chambon croissure are overcome in the Tavellette type which is universally adopted in modern methods of reeling. In this type the thread coming out of the thread guide passes over three small pulleys called croissure wheels fitted into the croissure frame. The reeled thread depends upon itself for application and effect of croissure. Ordinarily in practice the length of croissure or the twisted section is adjusted according to the size of the silk reeled and the speed of reeling. The length of croissure is short with fewer number of spirals for finer sizes, while it is longer and has more spirals for the coarser sizes as they can withstand a higher reeling tension.

The efficiency of croissure, be it Chambon or Tavellette, depends upon the pitch of the spirals as determined by the number of spirals per centimetre, and the angle of the croissure wheels. In the earlier machines the number of the spirals could be adjusted by altering the positions of the croissure arms.

Reels

The silk thread after leaving the croissure is wound in a series of superimposed coils on the reel. The important functions of the reel are firstly to draw off the baves from the cluster of cocoons in the end and help in the formation of a continuous thread, and secondly to wind up itself the thread of raw silk so produced. The size of the reels is not constant for all types of reeling machines. In the direct reeling machine the reel has a perimeter of 145–150 cm, whereas in the modern multi–end reeling machines the reels are smaller with a perimeter of 60–75 cm. In several types of old hand–driven machines, the reels were very large varying in size from 180 to 200 cm.

Similarly the design and constructional details of the reel vary according to types of machine. The reel of the direct reeling filature machine, which is also known as the standard size reel (having a measurement of 148–150 cm), has six ribs or reel bars made of wood which are spaced at angles of 60^0 (Fig. 26). Each rib is horizontally held on a pair of round iron spokes or reel arms radiating from the main reel axle. One pair of these can be shortened by releasing thumb screws there on so that the perimeter of the reel can be reduced for removing the reeled hanks when they reach the desired thickness.

Small reel

The small reels of the multi–end machines also have six ribs, usually made of wood and spaced at an angle of 60^0, but these are held on solid single arms or on the periphery of metallic discs of special design. In some machines the entire reel is made of pressed aluminium and each reel accommodates only one hank. On one side of the reel is provided a well polished round metallic ring which serves two purposes in reeling. It takes the brake load for stopping the reel and in re–reeling it serves as a thread guide for easy unwinding of the reeled silk from the small reel. Some reels have axle rods with a friction or clutch wheel fitted at one end while in certain other machines the reels have only a central bore for slipping over common reel carrier shaft. The silk reeled on small reels cannot be removed as hanks and therefore it is transferred to the standard reels of the re–reeling machine by a process of re–reeling or re–winding.

Primitive reeling equipment does not conform to any standard specification or pattern, (Fig. 27), and the size of the reel is considerably larger. It usually has four reel bars of wood spaced at angles of 90^0 and held on pairs of sturdy wooden or metallic spokes radiating from a substantially made axle. The axle generally carries at one end a handle for turning the reel. Each reel accommodates five to six or even eight hanks side by side. The large size hanks require to be reduced to standard size to facilitate subsequent winding.

Speed of reels

The production of reeled silk as well as its quality are largely controlled by the length of thread that is produced in a unit time. This depends upon the perimeter of the reel and its velocity. But the speed of the reel or rate of thread production should be carefully adjusted taking into consideration reelability of cocoons and the non–breakalbe filament length of the cocoon. Too high a speed of reeling should be avoided as it increases the tension on the thread being reeled and causes it to break frequently, thereby reducing the rate of thread production and increasing wastage. Similarly too low a speed, reduces the rate of production and impairs the qualities of cohesion and lustre of the reeled silk. It also reduces the effectiveness of croissure in removing the excess moisture present in the reeled silk. Ordinarily for good quality cocoons having more than six hundred metres of reelable fialment per casting, a thread speed of 120 to 150 m per minute is maintained in filature machines, which reel ten ends per basin. When reeling cocoons have a shorter length of silk filament, the number of reeling ends are proportionately decreased instead of reducing the speed, because proper speed of reeling ensures greater lustre and better cohesion of the reeled thread. In modern multi–end reeling machines designed to reel in sections of 20 ends, the speed of reeling is maintained almost at the same level provided the non–breakable filament length is not less than 800 m.

Traverse or Distributor

The silk even after leaving the croissure still contains a considerable quantity of water and the sericin is soft and remains wet and sticky. When silk in this condition is wound on the reel the defects of ribbing and plastering easily occur. These defects in the hank spoil the winding quality and make the winding operation halting and wasteful in material. Poor winding quality also considerably lowers the commercial value of silk. Therefore, in good reeling, utmost care should be taken to avoid occurrence of the defects of ribbing and plastering.

Avoidance of these defects was attempted by drying the silk completely in its passage from the croissure to the reel. For this purpose a special attachment consisting of an electrically heated long shaft with pulley like wheels on it, one for each thread, was placed horizontally in front of the reels. The reeled thread was passed over the hot pulley for quick drying before the thread was wound on the reel. Another method adopted was to reduce mill dampness and increase the length of the silk path between the croissure and the reel by passing the silk thread backward and forward on special pulleys so that silk might dry before reaching the reel. These measures were ultimately given up because quick drying on very hot surfaces spoiled the strength and lustre of the silk, and lengthening the silk path by zig–zag running of the silk over pulleys caused attrition which was found to impair the dynamometric properties.

Various modifications of the standard reel for avoiding the defect of ribbing were also tried, by providing skeletal and fenestrated ribs so that the hank was better ventilated at the point of contact with the wood, but this was not found practical enough for industrial adoption. Other experiments with ribs reduced to a minimum width gave results quite contrary to what was expected. The defect of ribbing was ultimately reduced to a considerable extent by adopting various modifications of the standard reel. A reel where the reel bars have rounded edges was found to give satisfactory results and such reels continue to be used in rewinding machines.

Grant reeling

A ratio of 0.656 between the movements of the traverse guide and the reel is maintained in some machines so that it is impossible for the thread to fall parallel except after the reel has made a large number of revolutions, because the traverse make 656/ 1000 of its forward and backward movement with each turn of the reel (Fig. 28). But in this method the disadvantage is that when there is a thread break, the broken end of the hank gets lost in the very close network of the hank and causes much delay in the knotting operation. In order to overcome this defect another system is generally adopted known as grant reeling. In this system each reel operates its own traverse mechanism consisting of a set of gears having specific ratios between them to obtain the particular pattern and number of webs or diamonds across the face of the hank as prescribed for the International standard hank. For instance in a combination of 13:24 gear ratio, for every 24 revolutions of the reel, the traverse crank or eccentric makes only 13 revolutions thus moving the connected traverse rod forward and backward 13 times producing thereby 13 diamonds or webs across the face of the hank as specified by International standards. This grant reeling technique is adopted in direct reeling as in the re–reeling machines. Re–reeling can be done easily and without wastage of silk only when the reeled silk is distributed in a slightly convex manner on the small sized reels used in reeling operations. Convex distribution is obtained by using a cam mechanism for driving the traverse. The special advantage of the cam mechanism is that any desired pattern or contour of the hank can be obtained by altering the profile of the driving cam (Fig. 29). It is this special advantage that has made cam mechanism so popular in the textile machines where the threads are subjected to high–speed winding or re–winding processes.

Whatever the mechanism of traverse, the advantages of proper distribution of silk on the reel are:

i) It enables quick detection of broken ends in the network of the hank and thus facilitates prompt repair of broken ends by knotting.

ii) Several parts of the hank can be kept separated by lacing when the hank is removed from the reel. This prevents entanglements of the threads in the hank.

iii) Defects and adhering dirt in the silk can be easily seen in the wide spread and webbed hank. This enables the easy and quick removal of the defects and dirt before skeining the hank.

iv) Because of the accurate distribution of the silk the defects of hard gum spots, ribbing and plastering will be very much reduced thus enhancing the winding qualities of raw silk.

v) Wide and webbed distribution also hastens drying of the silk.

(ii) Re-reeling

Direct-reeled silk, in spite of all the care taken in reeling, contains certain defects such as short lengths of fine sizes, broken threads, entanglements, hard gum spots, short lengths of loose threads, etc. These defects cannot be removed or rectified by repairs in the process of silk examination. These defects lead to poor winding and increased wastage of material, and consume more time and labour in the subsequent processes of silk throwing and twisting operations. The defects of direct-reeled silk are removed by a process of re-reeling of the silk already reeled on to standard reels of a re-reeling machine.

The re-reeling machine (Fig. 30) is a simple equipment consisting of an iron or wooden frame similar to the reel frame of the reeling machine fitted with a standard reel for grant reeling which can accommodate five to six ends. A number of enamelled or glass pigtail guide hooks are fitted at equal distances on the traverse rod. Thus in this mechanism each reel operates its own independent traverse and helps in obtaining a hank according to the international specifications. Each reel is served by a mechanical hand brake which when operated disengages a friction wheel of the reel from the drive wheel of the transmission shaft and stops the reel.

The lower part of the reeling frame has a rack attachment for supporting the swifts which carry on them the hanks from the direct reeling machines. Each swift is self-entering and designed to carry one hank. In between two swifts, a projecting partition board is fitted which extends up to the thread guide on the traverse. These partition boards prevent the formationof double ends in re-reeling caused by the flying broken thread of one hank getting attached to the running thread of the adjacent hank and thus getting reeled off with it.

Tension is given to the re-reeled thread by providing a tension rod in front of the traverse rod and parallel to it. The thread is passed over the tension rod before it is taken through the guide hook of the traverse and attached to the reel. Thread tension is essential for correct distribution of thread on the reel and for tight winding. In some machines cleaning knives are also provided for removing the adhering dirt on the thread.

Re-reeling is a simple but skilled operation. The hank from the direct reeling machine is carefully placed over the swift, after loosening the gummed threads at the reel points and at the plastered places. Sometimes the gummed threads are softened by wetting with mild wetting agents which do not discolour or weaken the silk. The thread end from the outer surface of the hank is taken over the suitably adjusted tension rod and through the guide hole of the traverse and attached to the reel. When the brake is released and the reels begin to revolve, the thread from the hank in the swift below is pulled and unwound to wind on the reels of the machine.

Thread breaks occur whenever a weak spot is reached in the thread and it cannot withstand the tension of re-reeling, and this allows the operative to remove the length of thin thread from the hank on the swift before uniting the broken ends and re-starting the rewinding operation. Likewise re-reeling is halted at places of discontinuity of thread in the hank enabling the operative to repair the thread by knotting the broken ends. The re-reeling helps in removing the defects in direct reeled silk.

Re-reeling from small reels

The re-reeling machine used for rewinding the silk from small reels is almost similar in all essentials to the machine already described used for re-reeling the large hank of the direct-reeling machine. The important difference is that in this machine, the swift rack is omitted because the silk is reeled directly off the small reel by placing the reels on the ground or on the platform provided in certain models. Some machines have also simple brushing or cleaning pads of velvet for brushing off from the silk thread, the loosely adhering wastes and dirt, when the thread passes between the pads, (Fig 31). The reel frames are generally encased and provided with heating arrangements inside to dry the re-reeled silk quality.

The silk on the reel is wetted by dipping the reel in water or mild wetting agents for sometime before re-reeling. The reel is then placed horizontally on the ground or platform with its rim side up and the loose end of the thread attached to the reel after taking the thread through the cleaning pads over the tension rod and through the traverse guide eye. As the reeled silk is not subjected to unnecessary handling, it is generally good and the workload of the operative is substantially reduced.

(iii) Silk Examination, Lacing and Skeining

The raw silk hank from the re-reeling machine is taken to the silk examination room for conducting visual examination of the silk and for preparing the silk hank for skeining and packing. Silk examination is generally done in a specially constructed rectangular hall running east to west and having sky lights of special ground glass windows on the northern side in order to obtain good diffused light. Artificial lighting is very rarely resorted to, because of the heavy cost in providing elaborate lighting arrangements.

The hank received from the reeling section is carefully stretched on silk examination racks or stands, and the reel points or "ribbing" at the places of the hank are opened carefully. This is done by holding the hank firmly in both hands held five cm apart with the hard ribbing in between the hands and twisting the hard rib one half turn while the hank is tightly stretched, and then gently rubbing the ribbed area till all the filaments are loosened. This operation should be done very carefully as carelessness causes damage to the hank. After the softening or opening of the ribbings, the easily removable dirt and other defects such as loose threads are carefully picked out and removed. Similarly long knots are properly trimmed by scissors. If there are any broken ends they are repaired by knotting as far as possible and all the obviously coarse and too fine lengths of thread in the hank are clipped and removed, and broken ends knotted.

After the silk hank has been cleaned the hank is laced. Lacing consists of passing a thread across the skein in such a way as to divide it into five equal parts with the purpose of keeping the threads in place to ensure the thread being unwound easily. Unlaced silk has threads in an entangled manner,and so the subsequent winding operation becomes too much interrupted due to frequent breakages resulting in reduced output of winding and increased wastage, (Fig. 32). Lacing is done with soft silk or cotton thread which can be easily snapped or broken by hand. The silk examiners are provided with necessary threads generally white thread for the three lacings and one fast coloured thread for securing the ends of silk in the hank using crochet needles and scissors. Different coloured threads are also used for differentiating the size of raw silk. All the silken wastes removed in the silk cleaning process are collected separately and sold later.

The cleaned and laced hanks are then skeining by a separate set of operatives.Skeining is done by twisting the hank several times and folding the hank upon itself in a number of spirals in such a manner that the silk threads in the hank are not ruffled or entangled in the subsequent processes of booking and bundling, and general handling of the silk until it is opened for use in the twisting and throwing operations.

In most reeling filatures, twisting of the hank is done by using a simple apparatus known as a skeining machine or a turner. One end of the laced hank is carefully passed over a short brass tube held in the palm of the operative. The operative holds the silk hand in a taut condition and gives several turns to the handle of the skeining machine. Then without removing the silk from the book (see below) the operative places his fingers at the centre of the twisted hank and folds the hank upon itself. Because of the twisting given previously the hank when folded turns by itself in spirals. The operative then unhooks the hank from the turner and skilfully slips through the loop the other end of the hank held in the palm. When this has been done, the end emerging from the loop is opened out and extended into a circle, the circular pattern of this extension is known as the flower or fiacco crown. This protrudes about 1.5 to 2 cm above the loop through which it has passed. The silk threads of the loop are carefully spread out in a fascia about 5 cm wide. The standard loop has five distinct spirals, in addition to the loop at the fold, the fascia and the fiacco. When the skein has thus been prepared, a slip of paper bearing the number of the basin from where it came (Fig. 33) is securely inserted between the spirals of the skein, and the skein is passed on to the next operation of booking.

Booking

The skeins are made into neat books of approximately equal weight and dimensions in a book–making machine. In a book there are eight skeins in the horizontal row and five in the vertical row. Each book is neatly tied with separate cotton bands at three different places and wrapped in tissue paper. The books are then carefully wrapped in thin cotton material first and then wrapped in Hessian cloth and packed into a bale of approximately 133 lb or 60 kg (net weight of silk). All bales are marked with the denier of the silk contained in them.

Productivity Estimation

Productivity or weight of reeled silk per reeling basin can be estimated by the mathematical formulae which is derived as follows:

$$\text{Total length of silk (L)} = Vtn$$

where V=Velocity of thread production
t=time set for reeling
n=number of ends

$$\text{Total weight of silk (W)} = \frac{L \times D}{9000} \quad \ldots\ldots (2)$$

where D=size of silk

Substituting Vtn for L in (2) gives

$$W = \frac{VtnD}{9000} \quad \ldots\ldots (3)$$

Example:

1. Size of silk reeled: 20/22 denier or average 21 deniers
2. Velocity of thread: 90 m per minute
3. Time set for reeling: 480 minutes or 8 hours
4. No. of ends reeled: 10

According to formula (3):

$$\frac{90 \times 480 \times 10 \times 21}{9000} = 1008 \text{ g (the productivity of the basin)}$$

Uniform and superior quality of cocoon for reeling is no doubt a necessary pre-requisite for ensuring peak efficiency of a man and his machine, resulting in stable production. But even when uniformly good quality cocoons have been issued for reeling to a section consisting of several reeling machines, individual variations in production occur among reelers in the same section, because of the interruptions in production due to reel stoppage which is not uniform for all basins. An on-the-spot study of reeling reveals that the stoppages of the reel are generally caused by the following:

i) Improper cooking of cocoons
ii) Imperfect brushing of cocoons and bave cleaning
iii) Croissure defect

In addition to these direct causes, other factors responsible for interrupted production are lack of timely supplies of boiled cocoons in adequate quantities, repairs to machinery, insufficient supply of steam, electric power failure, periodic removal of basin refuse, changing of water in the reeling basin, etc.

Thus the difference between productivity and actual production are the result of a combination of factors including the quality of raw material used for reeling, the skill of the operative engaged in the reeling operations and the performance of the reeling machines. The extent of the difference is determined by the total loss of time in reeling.

Recovery of Silk

Renditta as already defined is the ratio between the quantity of cocoons used and the actual quantity of raw silk obtained. Estimation of renditta of a lot of cocoons prior to its purchase is important as it indicates the appropriate price to be fixed for the cocoons under transaction. Systematic recording of renditta provides valuable data for planning cocoon purchases and production of raw silk besides revealing the trends of progress in sericulture and reeling industries.

The total weight of raw silk that can be produced from any lot is primarily determined not by the gross weight of silk in the cocoons but by the actual quantity of silk that can be recovered from it in reeling or inversely, by the total quantity of silken waste present in the bulk lot. As indicated earlier, wastes are eliminated at different stages in the course of reeling and the renditta of the lot is influenced by the incidence of wastes.

Silkwaste

All the cocoons included in the bulk lot may not be reelable and the unreelable cocoons form the first type of 'waste' in the bulk lot. The next waste is the unreelable portion or the silk shell like the floss and the pelade layers. A certain portion of the bave available for reeling is converted into waste in end-finding and bave-clearing. Thread waste occurs as a result of improper reeling, resulting in frequent repairs of the

broken ends of the thread. Thus it is obvious that the total quantity of waste involved in reeling raw silk not only reflects on the quality of cocoons but also indicates the operative's efficiency, or skill of workers handling the cocoons in the manufacturing process, and the mechanical efficiency of the reeling equipment used. The highest levels of operational efficiency of filatures are obtained by organising a cocoon testing and demonstration section for training the artisans.

Every large factory has a demonstration section where the Instructor explains new methods with appropriate demonstrations. The Instructors themselves keep in constant touch with the latest progress in research. Training of the operatives is undertaken with due regard to time and motion involved in the reeling operations. Time study is the accurate analysis of the time necessary to perform an operation or a particular part thereof. Every operation is carefully analysed into its constituent elements and timed with a stop watch. The total gives the time taken for the completed operation. From these figures it is possible to calculate fairly easily the actual time required for execution of a particular work. For example the Japanese have analysed the "Time and Motion" factor in working the multi-end reeling machine as follows:

Data — Total time for study	8 hours	
Quality of cocoons used	Medium (16% silk shell) & 800 m filament length	
Speed of reel	100 R.P.M.	
1. Taking new cocoons & placing them in the brushing basin	7.2 per cent of the time	
2. Gathering clear ends in the side basin and final adjustment for reeling	16.4 per cent of the time	
3. Feeding/attachment of fresh filaments to jettebout	43.5	"
4. Repairs to broken threads and restarting	6.3	"
5. Cleaning the reeling bath in removing the pupae and dropped cocoons	16.6	"
6. Miscellaneous stoppages	4.1	"
7. Idle time per operator	5.9	"

In the course of this analysis, a study is also made of the precise movements involved in the operation so that unnecessary movements can be avoided, and the necessary ones improved and systematised so that the required work can be completed in minimum time and with less physical strain. The Japanese, in fact, attach so much importance to this that the reelers are drilled regularly to become efficient reelers. When a fully trained reeler is at his job, there is complete harmony between the reeler and his machine and maximum efficiency of work results. One month of intensive training is usually sufficient to make the new recruits effective workers, though it would take a couple of months more to make them highly skilled workers capable of producing required qualities of raw silk at economic cost.

(iv) By-products of Reeling

The chief by-products of the reeling industry are mainly the silk wastes obtained at different stages of processing cocoons into raw silk and the pupae. These are valuable material giving substantial returns to the reelers by their sale. The appreciable returns obtained from them help the reelers to keep their end product, i.e. the raw silk, at competitive levels. In other words, they help in lowering the net cost of production of raw silk.

All the waste obtained in the course of reeling may be classified as follows:

(i) cocoon wastes (ii) reeling wastes (iii) winding wastes

Generally, the silk waste is known by different trade names in different countries. It is known as knubbs in England, frisonnette in France, strussa in Italy, curlies in Turkey, kibiso and bisu in Japan, and by several other names in India according to the area of production.

State	Name	Kind
Kashmir	Sarnac	I grade
"	Guddar	II grade
"	Neem guddar	III grade (including basin refuse)
Mysore	Filature waste	I grade
Mysore	Filature waste	II grade
Mysore	Cottage basin waste	I grade
Mysore	Charka waste	Short waste
West Bengal	Kotabaria	I grade
West Bengal	Farai	II grade

The bulk of the silkwaste is utilised in the spun silk or schappe manufacture. In India it is partly used for production of coarse hand spun yarn as a cottage craft. The coarse hand–spun yarn known as Matka yarn is largely produced in West Bengal and used in handloom weaving industry.

Pupae

The Silkworm pupae are very rich in protein and fat contents. They are used as manures and feed for cattle, fish and poultry. In many sericultural countries oil is also extracted from pupae by expression or by solvent extraction. The yield of oil is 22–27 per cent by dry weight. The oil can be refined and used for industrial purposes. The residue after extraction is very rich in protein content and vitamins. It can be deodorised and made fit for human consumption.

(v) **Anciliary Equipment**

Boiler: Steam is used in the filatures essentially for heating water in the cooking and reeling basins and for stifling the cocoons. Ordinarily a total of 100 lb of steam at 75 lb per cm^2 pressure would be required for every installed basin. The size of the boiler would, therefore, depend upon the installed capacity of the filatures. As the draw of steam will neither be constant nor regular in the filatures, the most important feature of the boiler should be quick generation of steam for prompt and continuous supply to the cooking and reeling basins.

Power: Electricity is undoubtedly the best motive power, although manual labour is also popular in the cottage sector. Each unit of twenty reeling basins made up of ten basins in each row should be supplied with an independent low horsepower (2 H.P.) motor. The advantages of this system are:

i) It can be directly applied to independent units without having to make elaborate arrangements for transmission of power drive.

ii) Particular units can be stopped or started with the aid of conveniently placed switches.

iii) Power supply to the several units can be measured separetly by providing electric meters connected with the circuit.

iv) Requisite speed variations can be obtained by the use of suitable motors or by providing suitable intermediary connecting pulleys.

v) Losses in power transmission and wear and tear are minimised.

vi) Maintenance costs are low.

vii) A motor can be very easily removed from position and a new one substituted without interfering with work in other sections.

(viii) Need for providing costly and heavy foundations is avoided.

Re-reeling machine: Ordinarily the ratio between reeling and re-reeling machines, when re-reeling is done from small reels, is one reel for every fifty ends; whereas it is one reel for every ten ends for re-reeling direct-reeled silk mounted on swifts.

Eprouvettes and Denier Scales: With the increasing demand for raw silk of uniform sizes the need for maintaining accuracy of the size of silk reeled has become a necessity. This is done by taking test wrappings from reels at random intervals when reeling is in progress, (Fig. 34), by using eprouvettes and denier scales. These pieces of equipment are essential for quality control. With one hand-operated instrument about 150 test samples of 112.5 m length can be weighed. The number of these instruments depends on the number of basins installed.

Silk examination stands: These are simple wooden racks for stretching the silk hank for examination, cleaning and lacing before skeining. On an average one stand with one operative is sufficient for 200 re-reeled hanks and 100-125 direct-reeled hanks. The number of stands is adjusted according to requirements, although with the advent of automatic reeling there is practically no need for handling the silk further, and this would completely eliminate personal error in handling.

Silk skeining machines: This simple small-sized hand-operated equipment is generally fixed to the work table. Ordinarily 300-350 skeins can be made in one day with one skeining machine and one operative.

Booking presses: These small, simple presses are required for binding a certain number of skeins to make a weight of 2 kg. With one booking press 60 to 70 books can be made in one day.

Testing appliances: A modern filature requires certain standard raw silk testing appliances. Firstly these help in maintaining effective control on the quality of raw silk during production and secondly enable the filatures to sort the product into qualities and grades before marketing. The testing equipment is very costly and a full complement may not be required for a commercial filature of medium or small size. The raw silk produced by these could always be tested in a State-organized and managed silk-testing and conditioning house. For purposes of maintaining control and check on the two essential qualities of evenness and winding it would be sufficient to have a winding frame for conducting a winding test. For conducting an evenness test a seriplane with necessary standard photographs and arrangements for dark room inspection of seriplane panels would be required.

Workshop: It is essential for every filature to have a workshop with necessary equipment to deal with day-to-day repairs in the factory as well as for manufacture of simple light parts of the several machines and equipment used in the filatures. This department should function as the maintenance department. Its duty is to ensure constant inspection and service to ensure top efficiency of the several machines and equipment installed.

Laboratory: The role of a scientific laboratory in a filature organization can not be over stressed. It is a mûst for every filature. The laboratory need not be very large, but it must be sufficiently well-equipped to tackle the various problems which frequently arise in the functioning of the filatures. The laboratory must include as an essential part of the test reeling equipment for day-to-day pre-testing of the quality of cocoons and their reelability and pre-determine the quantity and quality of raw silk that can be expected from a particular lot of cocoons, and the percentage of wastage that may be obtained. The results and estimates should be tabulated and given along with the cocoon lot issued for reeling. This should invariably be accompanied by technical suggestions for the guidance of the reeling department. The laboratory should also conduct experiments in reeling to obtain better reelability and recommend methods for application in the filatures. A well equipped laboratory is a valuable asset for ensuring efficient work in the factory.

Other ancillaries: These include cocoon racks, cocoon trays, baskets, floor mats, cocoon trolleys, buckets and platform scales for weighing cocoons, etc.

Water and Mill Dampness

Water plays a very important role in the reeling industry. Water is directly used for cooking cocoons, as medium for reeling and preparation of by-products such as silk wastes obtained in reeling. Apart from these direct uses, water is also used in boilers for generation of steam required chiefly for steam stifling of cocoons, heating the water in cooking and reeling basins, and for heating the reel box, etc. On an average about 50 gallons of water is used for production of every kilogram of raw silk.

The quality of water used in the reeling industry is of primary importance because not only does it influence the economics of reeling but also the quality of the raw silk produced. Water used in reeling must be clear as otherwise the suspended impurities adhere to the surface of the fibre and get fixed on it. The deposit would alter the colour and lustre of silk. Yellow silk reeled with ferruginous water not only loses its lustre but gets discoloured into ochre colour due to the deposit of ferrous salts on its surface. Turbid water is cleared by sedimentation and filtration processes.

Hard water is not used in reeling because when silk is treated in hard water at 60°C for about half an hour the hardness is reduced by nearly 50 per cent and the precipitated impurities stick on to the surface of the silk which is sericin. This makes ultimate degumming process difficult and uneconomic. Generaly taking into account the various effects from heating and absorption of matter from cocoons, water having about 18° hardness of which two thirds is temporary is to be regarded as the normal requirement for reeling.

Absolutely soft water is also not quite suitable on account of the appreciable release of acidic substances by the cocoons during the cooking and reeling operations. The pH in the silk reeling bath should be maintained between 6.8 and 8.4, and in the cooking basin it may go even upto 9 because the water will be near boiling point. Control of pH value as above enables the retention of the natural colour of silk in the reeled silk. Acidulated water is specially injurious to the colour if the natural colour is yellow. On the other hand, slightly hard water has a good solvent effect on the dried and hard sericin.

Just as water of a particular quality is required for reeling, water of a particular quality is required for the boiler. The boiler water should be soft and devoid of substances that cause corrosion of the boiler plates. If for some reason water cannot be softened before use in the boiler, certain commercial products called boiler compounds may be used with boiler water as they counteract corrosion by dissolving or softening the deposits.

Mill Damp

This refers to the humid mist which forms in a mill when the steam in the air condenses. The air in a filature inevitably becomes highly laden with the moisture rising from the various basins and the material immersed in them. The frequency with which saturation point is reached must be considerable, since at 22°C it requires only 20 gm of moisture per cubic metre or about 2.5 per cent of its volume for the atmosphere to reach that point.

Formation of damp is harmful for various reasons. The chances of such defects as ribbing and plastering in the skein are aggravated; further it makes working conditions very uncomfortable. Prevention of mill damp would be adequately attained simply by raising the temperature of the premises. But this, besides being uneconomical, may be harmful to the workers. More practical and convenient ways of reducing humidity is to expel the damp air or to introduce dry warm air. The former can be easily effected by sound natural ventilation of the premises.

Chapter 7

SYSTEMS OF REELING

The evolution of the reeling machines and the methods of reeling are briefly described below:

Dotorikikai: In ancient times a crude contraption known as dotorikikai was used for reeling in Japan. It consisted of a cylindrical piece of light wood about 12.5 cm in diameter and 60 cm in length. This was fixed on an extended axis loosely held at either ends of supports about 15 cm high. Close in front of the cylinder, which served the purpose of a modern reel, a crude oven, actually an open fireplace was lighted and a pot or can with water was placed on it and the water boiled. The cocoons for reeling were cooked in the boiling water and manipulated with a pair of wooden prongs. When the cocoons were cooked, the reeler gathered five or six filaments from as many cocoons and wound them on the cylinder after twisting the several filaments taken by rubbing the filaments between the palms. The reel was then turned to revolve. Reeling was not a continuous process but halting on account of the elaborate twisting of the silk filaments that had to be done before the silk was wound on the cylinder. The silk produced was crude, uneven in size and poor in cohesion and cleanness.

Tegurikikai: Later an improved model called "Tegurikikai" was used until about the middle of the last century. It consisted of a rectangular reel 75 cm in circumference with an extended axle resting loosely on upright supports. One end of the axle was provided with a bamboo handle for turning the reel. The height of the upright supporting the reel was fixed according to the convenience of the reeler. The reeler turned the reel with the right hand and manipulated the silk with the left, simultaneously drawing and twisting the drawn filaments and winding the silk on reels.

Zagurikikai: This sedentary type reeling equipment was introduced later. The circumference of the reel in this equipment was about 53 cm with four reel bars. The improved aspects of the equipment were (i) a bamboo distributor, (ii) a thread guide, (iii) 'V' shaped brass wire loops or brackets for application of croissure, and (iv) fixture of a wide mouthed enamelled basin over a well constructed oven in which coal or charcoal was burnt to avoid smoke. In this equipment two ends were conveniently reeled and the mechanical improvements effected in the equipment enabled quicker reeling of better quality of silk than in either Dotori or Teguri.

Ashibumikikai: Zagurikikai was followed by a modified reeling equipment modelled after the foot-reeling machine originally imported from Europe. It was simple in construction with considerable improvement over the equipment previously described. It consisted of a reeling table and a separate frame for holding the reel. The table and the reel holder are connected by a tie beam. The reel bench or table held a detachable reeling basin for boiling and reeling the cocoons. Three or four button threaders ware provided in a horizontal frame placed across and a few inches above the reeling basin. Above each threader in the vertical plane there was a series of three wheels for application of tavellette type of croissure. The reel holder frame held the reel, distributor and its mechanism and the main drive wheel. This drive wheel was connected to a treadle. By operating the treadle withfeet, the reels were turned. By using this machine, both hands of the reeler were free for easy and efficient manipulation of silk under reeling. The equipment itself was compact, light and portable unlike the other equipment described earlier where the reeler stood on one side and attended to reeling. In this case, the reeler sits on a bench built for the purpose, facing the reel bench in the passage between the reel bench and the reel frame.

Hand-reeling Machinery of Japan

As long as the preparation of filaments and casting of ends to keep the silk thread continue to remain manual operations, the process is known as hand-reeling as against machine reeling. Although the reels are driven by power and water is heated by steam, the reeling is still hand-reeling because the filament casting is dependent on the skill of the hand only. The cooking and reeling basin water is heated by steam from the central heater. The following features characterise the hand-reeling machinery:

In this method the cocoons are cooked separately in an open pan and reeling is done in a specially designed basin. The temperature in the reeling and cooking basins is maintained at different levels. The speed of the reels and the number of ends are increased appreciably to increase productivity. The reels are kept at the back of the reeler with facility for prompt knotting of broken threads and also to allow silk to dry before reaching the reel. Porcelain button guides, mechanical hand brakes for each reel and bevel gear system of traverse are incorporated keeping the general mechanism simple and the cost of construction low.

Because of the good quality of reeling cocoons, excellent construction of the machine, and conscientious and skilled workers of the reeling units, Japan was able to produce and export high grade raw silk. These machines continued to be the main stay of the reeling industry of Japan until the invention and industrial adaptation of the multi-end and automaic reeling machines, and are now used only for reeling double and inferior cocoons on a cottage basis.

(i) Direct Reeling Machine

The direct-reeling machine designed for reeling a silk hank of 150 cm circumference, in conformity with International standards, was largely popular in Europe. The silk reeled by this method can be directly used for winding operations which is the first operation in the conversion of raw silk into twisted silk yarn. This was the fore-runner of the hand-reeling machine of Japan described earlier, (Fig. 35). It differs from the hand-reeling machine in certain respects, e.g. the cooking basin for every set of two reeling basins was provided with automatic brushing arrangement. The reeling basin was served by a separate and preparation basin as well as a jettebout. The standard reels were encased with a built-in heating arrangement and each reel was provided with an independent traverse.

French and Italian scientists made significant contributions to the growh of the modern reeling industry. The old contrivances used in reeling were considerably improved both in design and construction. The direct-reeling machine with a number of mechanical gadgets laid the foundation for further improved models like the multi-end and automatic reeling machine. It would be interesting at this stage to mention the essential parts of this machine to understand the evolution of the most sophisticated reeling machines of Japan:

(1) Reel bench. (2) Separate cooking basin with mechanical brushing arrangement. (3) Reeling basin. (4) Croissure frame. (5) Preparation basin. (6) Reel box. (7) Standard reels. (8) Individual traverse mechanism. (9) Inbuilt heating arrangement for drying silk.

These machines were exported to other countries e.g. Japan, India, etc. even as early as 1867-68.The first organised filature in Japan was established at Tomioka in 1869 with European technical assistance. In India, these basins were also first introduced in Kashmir State where only univoltine cocoons are produced.

In India these European machines were introduced in other multivoltine states also in a modified form retaining the essentials. The modified versions were made locally with a view to keeping down the cost and also to suit the conditions peculiar to each sericulture area, which offers different qualities of cocoons of both pure and hybrid races.

India with diverse climatic conditions and a diverse fauna of silkworms offers a variety of reeling equipment and organizational patterns, from simple charkas in the cottage sector to the multi-end reeling machines in organised filatures as may be seen from the table:

Type	No of units
Filature machines	1878
Cottage machines	2901
Charkas	9215

(ii) Country Charka

The country charka is a manual-powered reeling machine extensively used in the cottage reeling sector of the Indian reeling industry. It is entirely home built by the owner with material available locally in the village and with the help of the village carpenter and blacksmith. It is generally installed in the back-yard of the cottage in a simple roofed shelter, (Fig. 36). Although the country charkas are not made according to any specifications of measurements, they are all similar in design and constructional details. Generally each charka establishment installs five to six charkas and each charka consists of three distinct parts, namely the mud platform, distributor and reel.

(i) **Mud platform:** This is rectangular in shape usually measuring about 60 to 75 cm high x 90 cm side and 120 cm long. The forepart has a built-in fireplace with a basin fitted over it. The other part of the platform is solid with a flat top intended for the reeler to sit and attend to the reeling operations. Sufficient space is left all round the basin on top of the platform for keeping such necessary equipment as a small earthenware pot for cold water, straw brushes or waste-removing sticks, and cooking ladles. The basin is of thick copper sheet and is generally of circular shape measuring about 45 cm to 50 cm in diameter and 20 cm to 22.5 cm in depth. Occasionally instead of a copper basin which is comparatively costly, one half of a vertically bisected earthenware pot is used. The basin is buried up to its brim in the mud platform with a spacious part of the basin's underside exposed to the fireplace below. The basin is used for both cooking and reeling operations.

Each basin is served by a crude thread guide commonly called "Tharpatti" which consists of a metallic strip about 5 cm x 15 cm provided with a number of apertures in it. It is securely fixed at the end of a thin long stick leaning against the front edge of the mud platform. In position, the Tharpatti overhangs about 15 to 20 cm above the front rim of the basin.

The fire place, which is not provided with a grate or ash pit, is generally built for burning firewood or dry twigs. In some places the fireplace is designed for burning paddy husk, dry peanut shells, etc. At the opposite end of the opening into the fire place is provided a chimney for escape of smoke. This is commonly made of a tin plate rolled into a tube. Sometimes ordinary burnt clay drain pipes are used instead.

(ii) **Distributor:** This is a simple device consisting of a crudely made eccentric wheel which in operation revolves on its vertical axis and drives the wooden traverse rod backwards and forwards. The traverse rod is aligned parallel to the front side of the platform and stands about 20 to 25 cm above. The eccentric wheel is driven by an endless cord-belt from the reel passing over the constricted part of the eccentric wheel. The traverse rod is provided with a number of loops of thread or bent wire along its length at regular intervals to serve as thread guides for the reeled threads passing through them on their way to the reel. So, when reeling is in progress, the traverse moves briskly to and fro in front of the reel and distributes the reeled silk on it in cross winding.

(iii) **The reel:** Only one long reel made of thick sections of seasoned wood is provided for each basin. Its circumference is unstandardised and ranges from 150 cm to 225 cm in different charkas although the popular circumference is 200 cm. It can accommodate four to five ends.

The reeler sits perched upon the platform facing the basin and the reel. When water in the basin reaches boiling point the reeler takes a handful of cocoons and cooks them.

After removal of floss and clearing the floss, a required number of baves from as many cocoons are taken and thread formed by employing chambon type of croissure. The reel is rotated manually by a separate turner and generally two or four ends are reeled.

The working conditions in a charka are far from satisfactory and its does not allow production of highgrade or finer quality of silk. In order to overcome the deficiencies inherent in charka, an improved reeling machine known as a domestic machine has been evolved and introduced as a compromise between the crude charka and the filature hand reeling machine. While retaining its rural character and without affecting the scope of employment, it is a versatile device for production of improved quality of raw silk to meet the increased demand for better reeled silk.

In West Bengal, Ghai machines similar to charkas are in use. Some attempts, however, were made to popularise the foot-reeling machine in the interior parts of the Sate for establishments using small quantities of cocoons. This machine was used here and there in undivided Bengal long ago by very small-scale reelers. This, however, did not become popular. The foot-reeling machine has its origin in Japan and consists of a bench which holds an integrated basin, a platform below it for placing a charcoal stove, a croissure frame of simple construction above the reeling basin for application of tavellette or chambon type croissure, (Fig 37). A small feel frame is placed a little away – some 60 cm to 75 cm from the basin frame – which carries in it either a single long reel of small circumference or two or three small reels slipped over a long shaft. The reel or the reel carrier shaft has at one end a friction wheel resting on a larger wheel fitted on a shaft below. The lower shaft carries a large wheel outside the frame to which a foot pedal is attached. The reel frame is provided with a small wooden seat facing the reeling basin for the reeler to sit. The reeler operates with his foot pedal placed conveniently below the seat which turns the reels.

Both cooking and reeling are done in the same basin, which is designed for reeling from two to four ends. The main shaft of the reel frame operates a simple traverse for distribution of silk on the reel. The reeled silk has to be re-reeled.

The foot-reeling equipment too has undergone several modifications and the one that has undergone a radical change is the foot-reeling machine with the reels brought in front of the reeler and placed a little above the reeling basin as in the modern multi-end reeling machine. Except that this change in design makes for compactness of the machine, there are no other alterations.

In the place of foot reeling machines, an improved reeling machine similar to cottage machines has been introduced which provides the cottage reeler with the essentials of modern technique and meets the functional requirements for a standard reeling process. The machine is designed for reeling on one side and re-reeling on the other side.

(iii) **Domestic Machine**

The domestic machine was evolved in Mysore State sometime between 1925 – 1927 to make better and more economic use of the steadily improving qualities of reeling cocoons. It is an assembly of three separate but functionally connected parts namely the cooking unit, the reel bench and the reel box, (Fig. 38).

(i) **Cooking unit:** The cooking unit consists of a masonry structure of a convenient height in which several – usually four – cooking basins are fixed in a row. The basins are generally double pan type similar in design to the cooking basins used in filature reeling machines. The oven is well constructed with grating and ash pit, and a chimney for exhaust of waste gases from the oven. In the path of the exhaust gas passage or fluea fairly large metallic water drum is fixed to serve as hot water supply source to the reeling basins. The cooking unit is usually located a little distance away from the reeling unit to prevent the heat and smoke from the cooking oven causing disturbance to the reelers.

(ii)**The reel bench:** It is a simplified basin from the original European design and its size is restricted to actual requirements. Generally each unit consists of four to five reeling basins. The table top is usually spacious and provides sufficient accommodation for keeping such necessary reeling equipment as water mugs, waste collection frames or even small brushes, ladles, etc. The reeling basin which is firmly fixed in the table is made of copper sheet and the dimensions of the basin are about 45 x 25 x 7.5 cm. Hot water for the reeling basin is supplied through taps drawn from the drum fitted on the cooking unit. In some models of the domestic basins the reeling tables are made in moulded cement concrete and the basin in glazed stone ware.The metallic Croissure frame and drive wheels on the transmission shaft are made of seasoned wood.

Each basin is designed to reel from four to six ends. To facilitiate easy attachment of filaments jettebouts are provided for each basin. In some machines the jettebouts have been replaced by ordinary porcelain button thread-guides mainly with the object of further simplyfying the machine and reducing its cost. Each basin has its independent croissure frame designed for application of tavellette croissure.

(iii)**The reel Frame:** This is an angle-iron or wooden frame fitted about one metre away from and parallel to the reel bench. The height of the reel bench is generally kept at about 150 to 170 cm from the ground. This height enables the knotter to move about freely in the passage between the reel bench and the reel frame and attend to the repairs by knotting the threads that break frequently in reeling. The reels are of standard size and pattern as prescribed for International standards. They are driven by corresponding drive wheels fitted on a common transmission shaft. At one end of the transmission shaft, the traverse mechanism consisting of the required gears, and at the other end, one handle, are provided. Each reel is served by a braking mechanism of simple design.

(iv) **Cottage Machine**

In the post war period, the domestic machine was followed, in keeping with the general trend of development of the reeling industry, by an improved machine popularly known as a Cottage machine patterned on the lines of the Japanese multi-end machine imported in 1951 by the Central Silk Board for experimentation, (Fig. 39). The Cottage machine is characterised by overhead small reels and separate equipment for re-reeling, (Fig. 40). The rest of the details are similar to the domestic machine described earlier.

(v) **Multi-end Reeling Machine**

The multi end reeling machine came into industrial use about forty years ago.It was evolved in Japan to make better and more economic use of the superior quality of reeling cocoons produced by the country's sericulture industry as a result of the application of the results of research in moriculture and silkworm rearing, (Fig. 41). This machine with required modifications to suit local conditions has been adopted by most of the sericulturally progressive countries.

The multi-end machine has for its basic principle slow speed reeling and thread production on small reels at a large number of ends per basin. Slow speed reeling reduces tension on the thread and minimizes the thread breaks,leading to increased thread production. Reeling on a small reel makes the subsequent process of re-reeling easier and less wasteful in material, time and labour. Provision of small sized reels has also enabled the designers to incorporate into the machine certain ingeniously devised mechanical devices to aid production of improved quality of reeled silk.As a result of careful time and motion studies involved in the performance of reeling operations, the machine has been made compact and at the same time comprehensive so that the reeler is not unduly strained physically in performing the reeling operations. In essence the changed concept of reeling technique from the earlier direct reeling system, has brought about a radical change not only in the design and construction of the multi-end machine, but in the operational technique as well.

Design: The multi-end machine is characterised by an outstanding feature, i.e. the cooking unit which is a specialised machine for cooking the cocoons automatically and preparing them to suit the sunken system of reeling. The reeling unit itself is composed of two parallel rows of large sized reeling basins with their complementary set of overhead small reels. The reel bench is of convenient height to enable the operative to work sitting on a stool or standing according to whether the machine is a 'sitting type' or 'standing type'. The sitting type provides for reeling twenty ends per reeler and the 'standing type' for 20 ends and above per reeler. The standing type machine has slightly higher level reeling table to prevent the reeler from having to stoop over the basins.

Basin: The basin is shallow being 10–12 cm deep, long and rectangular in shape with the inner and outer corners and edges well rounded. It is commonly made of porcelain and tinted. The basin is internally divided into a number of compartments, each designed for a specific function such as (i) brushing (ii) end gathering of baves (iii) reserve stocks (iv) unreeled or partly reeled cocoons (v) a long troughlike chamber for reeling ends, and (vi) waste and pupae collection. The basin is served by a built-in overflow drain.

The porcelain material is ideal to prevent action of heat or chemicals used for reeling. Tinting provides a contrasting colour for the cocoon filaments which facilitates quick detection of the number of cocoons at each end. The combined effect of multi-chambering and using porcelain material for the chamber helps in proper maintenance of the required temperature of the reeling bath for a longer time. Multi-chambering is advantageous in maintaining water in the reeling trough of the basin in a clear, limpid condition and undisturbed by agitation caused in the several other compartments of the basin during the brushing and bave-cleaning operations. To facilitate reeling of a large number of ends each basin is provided with the required number of jettebouts. Provision is made for application of tavellette croissure.

Reels: The reels of the multi-end reeling machine are of small size having a circumference of 60 or 75 cm in different machines according to design of the particular machine. The reel is made of light metal or compressed hard wood frame having six reel bars made of hard seasoned wood. Each reel has on one side a rim of round stainless steel or brass encircling the reel bars. Each reel is designed to wind upon itself only one hank. Thus each basin is provided with as many reels as there are reeling ends in the basin. The reels are slipped over a common reel carrier shaft which is driven by connecting gears from the main transmission shaft. Generally two reel carrier shafts each for ten reels are provided as this avoids sagging of the shaft and also facilitates better reeling performance. The reel carrier shaft is provided with a mechanical brake to stop the whole series of reels on it whenever it is necessary, otherwise, each reel can be stopped by operating the stop motion device provided for each reel. This device is simple in mechanism and delicate in construction. There are several types of mechanism but all operate on the principle of tension of the thread being reeled. Variations in tension due to occurrence of variations in size of the reeled thread or occurrence of obstructive wastes, nibs, slugs, etc. on the thread cause the automatic stop motion to function and bring the particular reel to a halt. This device is of great advantage to multi-end reeling as it helps in production of a clean thread of uniform thickness. As each reel is served by an independent automatic brake thread production on the other ends can go on without interruption even when a reel is stopped for repairs. The reels are encased with heating arrangements inside for quick drying of reeled silk.

A cam-type traverse mechanism is provided in this for obtaining a slightly convex surface of the hank on the reel with narrow and greatly elongated webs along the circumference of the hank. This type of distribution is very advantageous for quick detection of the broken ends and smooth re-reeling.

Ordinarily in all reeling machines porcelain button thread-guides are used for removing the adhering dirt on the thread passing through the tiny aperture in the button. In some multi-end machines, attempts have been made to replace the porcelain button by silk cleaning knives. The silk cleaning knife is really a slit piece of flat polished steel with a side screw for adjusting the width of the slit. The advantage of this is that the silk thread can be easily slid into the slit from the open side, and the slit narrowed or widened according to the size of the thread being reeled. These machines are also provided with speed regulators for regulation of speed to the particular quality of the cocoons under reeling.

The machine is generally sturdy and rigid, and friction in all the movable parts is reduced to the minimum by provision of suitable bearings and precision parts so that when the machine is in commission it is vibration-free and comparatively noiseless. Absence of vibration ensures better durability and noiselessness eliminates one of the causative factors for fatigue and decreasing efficiency of the operators.

The main objectives of the multi-end machine are three-fold, i.e. increased productivity, reduced wastage and superior quality of reeled silk. These objectives are attained by a combination of mechanical perfections of the reeling machine and the technique of preparing the cocoons for reeling. The sunken system of reeling is adopted in this machine. Silk reeled has to be re-reeled on standard reels of the re-reeling machines.

(vi) Details of Automation

Automatic Reeling Machine

In Japan an automatic reeling machine was originally invented in 1901 and continuously developed until 1941, but the new invention was not found to be convenient for reeling 13/15 denier raw silk, which was the most popular size in demand, and the machine was not industrially adopted. It was only from 1946 onwards, when the demand switched to 20/22 denier and simultaneously there was a sudden demand from labour for higher wages, that it became necessary for Japan to adopt automatic reeling machines. Since 1952 these machines have increased in popularity and currently the bulk of raw silk production in Japan is from automatic reeling machines, (Fig. 42).

Automatic reeling machines were also invented independently in Italy and France. It is said that an American engineer by the name of Edward William Serrel, invented an automatic reeling machine in 1880–1885. The machine was served by an automatic size regulator which was operated by the tension of the reeled thread. Later Bacinella Floruzzi derived another type of automatic machine which had a device for maintaining a constant number of cocoons in the reeling end. Rene Azemand invented an apparatus for reeling which could adjust the size of thread by the change in elongation. In 1925, the Ba Ca Pa type machine, which was originally invented by Balbiarin Carnovali and Panzela, was completed in Italy.

There were several other automatic reeling machines but none of them could be developed enough to produce raw silk superior in quality to that reeled with the multi-end reeling machine.

As the name suggests the reeling of cocoons is done by mechanisation through various processes involved in cocoon boiling, brushing, end picking, end feeding and reeling of filaments from the cocoons. In the evolution and designing of an automatic reeling machine spectacular strides were registered after 1950 when more and more electronic measuring aids came into use in the field of industrial research and planning.

Automatic reeling machines currently in use perform the following operations automatically:

(a) **Size controlling:** There are two systems for controlling the size of thread. One is the constant size type and the other is the fixed (cocoon) number type. The former is further divided into two types, in one the friction between the reeling thread and the size controlling spiral is utilized, and in the other the stretching stress of reeling silk which changes according to size is used. These machines are adopted not only in Japan, but also in certain other countries like Italy, Russia, South Korea, etc. Recently a new denier controlling mechanism has been introduced which can be conveniently used in fixed size type of reeling machines, in which the size of thread is controlled by the change of the friction of reeling thread passing through a slit between two glass, or fine nylon, discs.

(b) **Feeding the end of cocoon filament:** The apparatus for feeding the cocoon is a very important mechanism in the automation of silk reeling and is of two types. In one, the apparatus for feeding the ends circulates around the reeling parts as in the machines of Katakura Industry Co. Ltd., Fuji Precision Machinery Co. Ltd., and in the other, the apparatus for feeding the ends are fixed in position as in the machines of Gunze Silk Reeling Co. Ltd., and Keinan Kyodo Sanchi Co. Ltd.

(c) **Supplying cocoons to the feeding apparatus:** When the size of the thread becomes finer, a new cocoon is automatically sent from the supplying apparatus to the feeding apparatus. There are several kinds of apparatus such as the magnet type, spring type and cam type.

(d) Finding ends of cocoon filament

(e) Gathering the dropped cocoons

(f) Removing the pupae or knot attached to the thread by stop-motion mechanism

(g) Servicing the reeling basin:

(i) by removing the pupa

(ii) by separation of the reelable dropped cocoons from the used up cocoon

(iii) by adjustment of the temperature of the reeling water.

Outline of several kinds of automatic machine

Reeling itself is a mechanical operation in the automatic reeling machine. Size of raw silk is controlled by a device which automatically picks up the cocoon filaments and attaches them to the end which indicates a thin size and thus enables reeling of an uniform size of raw silk. The operative must, however, find the ends of the cocoon filament and arrange them in order so that they are ready to be removed to the cocoon-supplying apparatus. The automatic reeling machines which are used industrially in Japan, can be classified according to the mode of control of size as follows:

(1) **Fixed size type:** The automatic reeling machine of Katakura K.8 type was invented in 1929 and was industrialised in 1935. Thereafter several aspects of it were improved. For a brief period during the war research was suspended and the K.8 type machine was constructed again in 1951. This machine consists of two units of basins each with 200 threads, set up side by side with the cocoon carriers moving around the main part of the machine. The new cocoon basin and the dropped cocoon basin are on each side of this machine. The dropped coccons are collected from the reeling basin and are carried by a conveyor to the dropped cocoons basin for re-end-finding. This machine is served by such advanced devices as a variable-speed motor, traverse, cocoon conveyor, stop motion of small reel, rotation calculator, etc. which make the machine highly efficient. The new and dropped cocoons are gathered and moved forwards to the end-finding apparatus. When the carrier passes by the side of the end gathering basin, the cocoons with their ends arranged are readily supplied to the carrier which will feed the reeling end whenever they are required.

Pupae and the dropped cocoons are collected at both ends of the machine by the pupae conveyor which goes back and forth behind the conveyor of dropped cocoons and are put into it by the action of a small bucket.

The parts of one set of this machine are as follows:

Number of ends of reeling thread	.. 400
Number of fixed size regulators	.. 400
Number of carriers	.. 58
Total length	.. 24.18 m.
Width	.. 1.35 m.
Height	.. 1.55 m
Efficiency of picking up filament per one set	.. 3225 per minute
Winding velocity	.. 80–90 m. per minute

Number of workers per one set —

Searching worker	.. 2
Gathering worker	.. 2
Managing worker	.. 1

(2) **Fixed Number (of cocoons) type:** There are two kinds of machines which are used industrially in Japan. The outline of these types are as follows:

(a) Y.M. Keinan type automatic reeling machines: One complete machine consists of ten sets of the usual multi-end reeling machine of 20 ends and is operated by two workers. At present there are two methods of feeding. Constant number of reeling cocoons in one thread can easily be maintained at high operational efficiency of 95 per cent.

The mechanical parts of this machine are:

(i) Gadget for automatically finding ends of cocoon filaments.

(ii) This gadget consisting of five brushes which move around an axis in a round cocoon basin is set at each end of the machine. It is able to arrange 130–150 cocoons per minute.

(iii) Gadget for automatically feeding the filaments of raw cocoon to the reeling threads.

The dropped cocoons are moved to the dropping cocoon detector, which works by electric mechanism so that the cocoon supplier can immediately release one cocoon to the feeding apparatus.

(iv) Gadget for automatic cocoon-supplying basket.

The cocoons with their ends arranged move from the end-finding basin to the automatic cocoon-supplying basket. The basket containing about 50 cocoons travels to the reeling machine. A worker initially provides a few cocoons (10–15) to the feeding apparatus, which is fixed in position in front of each reeling thread.

(v) Device for conveying and assorting the dropped cocoons.

The dropped cocoons and pupae which pass the feeding section are forwarded to one place by a conveyor belt and the reelable dropped cocoons are automatically separated from pupae and moved forward to the end-finding basin, and the pupae are discharged.

(vi) The speed regulator for controlling the speed of the reels.

This is also provided for each 100 threads and sensitive adjustments are possible.

The automatic reeling machine was initially designed on the fixed number of cocoons per end but later the fixed size reeling machine was developed and it has become universal owing to its superior and satisfactory performance. Continued research to improve the efficiency of the machines and also the continued acute shortage of labour in the reeling mills has promoted the growth of more efficient machines. Further studies for utilising the computer on the automatic reeling machines to control the quality of the raw silk are under way. The comparative performance between the conventional multi-end machine and the Tama automatic reeling machine can be judged from the data below:

Description	Conventional machine	Automatic machine
Actual cocoon feeding capacity for 20 reeling units (times/min)	12	30
Reeling speed (metres/min)	53	131
Production amount for 20 reeling units (grammes/8 hours)	1,030	2,580
Production amount for 400 reeling units (kilos/8 hrs)	20.60	51.60
No. of direct operatives for obtaining the above amount	20	8
Production amount per operative	1,030	6,450
Index number of production efficiency per operative	100	626
Grade classified by International Standard	B A	2A or above

Generally for reeling 20/22 denier size silk, the cocoon characteristics required are as follows to give the even size of 20.5 deniers.

Length of cocoon filament	.. 1.000 metres
Reelability percentage	.. 70 per cent
Length of non-broken cocoon filament	.. 700 metres
Size of cocoon filament	.. 2.56 deniers

The present automatic reeling machine perfected during the 1950s' was adopted all over Japan. Its development has been phenomenal between 1952-69 as the following data shows:

	1952	1957	1962	1969
No. of filatures	7	62	161	157
Basins installed	1,040	5,123	11,644	14,067
Percentage of all basins	2.1	11.4	50.4	94.3

With the automatic reeling machine having taken a practical shape in 1950, there were only seven filatures with 1 040 basins accounting for 2.1 per cent in 1952, whereas by the end of 1969 all the 157 operating filatures switched over to automatic reeling machines accounting for 94.3 per cent of the total installed capacity of basins. In fact conventional machines like the multi-ends and zaguri remained

idle and therefore the automatic reeling machines formed nearly 99.5 per cent of the total active basins by the end of 1969.

Some leading manufacturers of Japan claim that their automatic silk reeling machine could be used for both superior and inferior qualities of cocoons.

Chapter 8

RAW SILK TESTING & CLASSIFICATION

In sericulturally advanced countries raw silk is tested and graded according to specified and accepted standards before marketing. This has been considered so important for the welfare of the silk industry that special organisations popularly called Silk Conditioning and Testing Houses have been established at considerable cost. These are so called because they not only conduct qualitative tests but also find out the actual mercantile weight of raw silk by subjecting raw silk to a process called conditioning. Conditioning essentially consists in desiccating the silk completely by exposing the silk to the action of dry hot air at a specified temperature in a specially designed conditioning oven or conditioning chamber. Desiccation or Conditioning is necessary because of silk's highly hygroscopic nature and to prevent fraudulent transactions.

The importance attached to Testing and Classification can be properly appreciated by the fact that in 1915 a prize essay competition was held under the auspices of the Silk Association of America. In 1921 and 1927 two raw silk classification committees were set up. These committees toured the leading raw-silk producing countries like China and Japan. Later two International Technical Conferences were held in Yokohama and New York, in 1927 and 1928 respectively. The important raw-silk producing countries of the world namely, Japan, China, Italy and France and the important silk consuming countries, America and England participated in the conferences. After prolonged and detailed discussions the standards for testing and classification methods were finaly adopted. The clasification is based upon the three major characteristics of evenness, cleanness and neatness supported by size deviation, strength, elongation and winding. The classification depends upon the scientific methods of testing samples properly drawn from lots of raw silk tendered for testing.

Advantages of testing and classification are obvious and numerous. The more important of them are:-

(i) Finding out the correct mercantile weight of raw silk by the process of conditioning avoids confusions and misunderstandings between the seller and the buyer.

(ii) Testing and classification ensures equitable transaction. Raw silk is one of the highest priced textile materials and neither the purchaser nor the seller can afford to have satisfactory transactions without proper analysis of the quality.

(iii) As raw silk would be tested and graded by an impartial organisation and each graded lot would bear a detailed certificate of quality, it would enable even a distant purchaser to obtain the exact quality by merely commnicating by letter to the seller the specifications of quality required.

(iv) It reveals to the reeler the preference of the purchasers for particular qualities and thus guides the reeler to plan production of only the required qualities in demand.

(v) As the quality of raw silk depends upon a combination of factors, like the quality of cocoons, reeling technique, the type of machinery and equipments used, and the skill of the operatives, the results of testing provide scope for scientific investigation into the causes for the defective aspects as well as the superior aspects of raw silk. The investigations would lead to evolving remedial measures to avoid recurrence of defects, and also measures for further improvement of the quality, and thus help to follow a system of quality control of production and marketing.

(vi) Testing and grading directly help to measure the progress of the reeling industry in particular and the sericulture industry in general, and thus open scope for research and development to ensure strengthening of links of the industry.

The Object of Testing:- The object of testing is to test the quality of raw silk and to determine the grade by the results of quality tests for the purpose of establishing standards.

Definitions:

(i) Raw Silk:

This is the thread reeled from several cocoons and is understood to be a continuous thread from beginning to the end of the skein.

(ii) International Standard Skein:

Should be 148–150 cm (58"–59") in circumference with ribbing not more than 2 cm at any one of the six ribs. The skein must be free from hard gum spots, and may have from eight to thirteen clearly defined diamonds across the face of the 7.5 cm wide hank. The weight of the skein should be 65–70 gm up to 12 denier; 70–85 gm up to 24 denier; 80–90 gm up to 32 denier and 90–100 gm above 32 denier.

(iii) Denier:

A weight equal to .05 gm (5 centigrams) as per International agreement adopted at a conference in Paris in 1900. The size of the thread is indicated by the weight of a 450 m skein in deniers, i.e. if a sample of 450 m silk thread weighs 0.05 gm it is said to be one denier (or 9 000 m would weigh 1 gm).

(iv) Standard Condition:

The condition in which raw silk contains moisture equivalent to 11% of the absolute dry weight of raw silk is called the standard condition of raw silk.

(v) Standard Bale:

60 kg or 132.3 lb. This unit is called a picul.

(vi) Standard Atmosphere:

Relative humidity 65% and temperature 25°C (78°F). Tolerance ± 2% R.H., ± 2°C. But variation during any one series of tests should not be greater than ± 1°C.

The procedure and methods of testing and grading as adopted at the 2nd. Technical Conference in Yokohama are outlined in the International Standards for testing and grading Far Eastern Raw Silk published by the Japan Silk Association. Italy and India are also following their own standards largely based on the International standards but suited to conditions obtaining in their respective countries. The tests fall under two categories, visual and mechanical – visual tests:

(i) Lot uniformity for colour, lustre and handling.

(ii) Seriplane tests examining the raw silk against a black background under standard conditions of illuminations.

Mechanical tests:

(i) Winding

(ii) Size test

(iii) Maximum Deviation test

(iv) Average-size test

(v) Evenness variation test

(vi) Cleanness test

(vii) Neatness test

(viii) Teanacity and elongation test

(ix) Cohesion test

(i) Standard Testing Appliances and Equipments

(1) Winding Frame:

The winding frame should be capable of being adjusted to a winding speed of 110, 140 or 165 m per minute. It should be equipped to drive the bobbins from both ends and run smoothly at uniform angular speed. Swifts should be automatic, self centring pin hub swifts and weigh about 530 gm (Fig. 43). Bobbins should be smooth and well balanced so as to give regular tension and uniform angular speed. The dimensions should be: diameter of head 60 mm; diameter of barrel 38 mm; length between heads 85 cm; weight 105 gm. The winding frame is used for conducting the winding test, and also for loading the bobbins with raw silk to be used for conducting the winding test and in subsequent tests.

(2) **Sizing Reel:**

The machine for making the sizing skein should have a reel of 1.125 m in circumference (400 revolutions will yield 450 m of thread) revolving at a uniform speed of 300 RPM, provided with a dial showing the number of revolutions and equipped with an automatic stop motion to stop the reel immediately in case the thread breaks or when the skein is complete.

(3) **Balance:**

A balance for determining the total weight of sizing skeins should have a sensitivity of 5 mgm and a capacity of 50 gm.

(4) **Scale:**

The scale for weighing the sizing skeins should be of the quadrant or other suitable type and have the capacity and sensitivity as shown below:

Capacity	Sensitivity
40 deniers	.25 deniers
80 deniers	.5 deniers
160 deniers	1.5 deniers
400 deniers	2.5 deniers

(5) **Seriplane:**

This is a machine frame intended and designed to rotate an Inspection Board in such a manner that the raw silk threads of fixed length can be wound upon it with uniform speed of 100 RPM only. When excessive breaks are observed the speed is reduced to 80 RPM. The machine is equipped with a device to secure uniform tension on the thread, and is generally equipped with a counter indicator to show the number of raw silk threads wound on the panel.

The Seriplane has provision for accommodating ten "filled bobbins." From each bobbin the thread is taken and after passing through several guides to maintain proper tension, the loose end is attached to a clip on the narrow side of the panel or blackboard. Thus ten different panels can be wound on the blackboard.

The threads are distributed on the panel or board only in one direction by means of a special mechanism which lays the silk threads in groups of about 13 cm in width. The speed of the board determines the closeness or sparseness of the thread on the panel.

Panel:

This is a section of raw silk 127 mm wide by 450 mm long, uniformly wound from a bobbin on to an Inspection board.

Inspection board:

This is a flat board one metre in circumference upon which the Inspection panel is wound. It has a uniformly flat black surface without streaks or bars or other imperfections which might influence the estimator or give a false effect.

Standard Photographs:

These were prepared by the Silk Conditioning houses of Yokohama and Kobe. Standard photographs of varying degrees of evenness to which percentages are applied for comparison with seriplane panels were first prepared and introduced for adoption by all silk conditioning and testing houses. The evenness standards of testing and classification had a bias for meeting the requirements of hosiery manufacturers. But these were revised in 1962, replacing percentage by the variation standards. The variation standards are followed only by Japan at present while the percentage standards are followed in India, Italy and other countries.

The standard photographs are prepared for

(1) Evenness tests — Standard variation photographs indicate the intensity of variation.

(2) Standard evenness standard photographs indicate the relative values of evenness expressed in percentages.

(3) Cleanness tests: Standard photographs indicate cleanness defects.

(4) Neatness tests: Standard photographs indicate neatness defects.

The standard photographs are used for comparing the actual samples taken on the inspection board of the Seriplane. The examination or inspection is conducted in a specially constructed room called the Inspection room.

Inspection Room:

This is a room specially designed for conducting the inspection or examination of test panels. The inner walls of the room are painted with mat pale grey paint, while the rest of the floor, ceiling and internal surfaces of screens are painted flat white.

The viewing panel is fixed on a special rack called the Inspection rack. The boards are fixed in such a manner that each can revolve on two central pivots at its extremities.

The lighting equipment consists of two vertical reflectors for evenness estimation with chromium reflecting surfaces, corrugated and shaped so as to produce a diffused light of uniform distribution. Each reflector should be 152.5 cm long and fitted with six 50-watt bulbs. The reflector should be fixed in such a position as to provide indirect and reflected light only for examination of the panels. The lowest lamp is one foot above the floor level. These reflectors are provided with independent switches.

The horizontal reflector with either a corrugated chromium surface or a plain reflecting surface is furnished with six 100-watt lamps at equal distances apart. In some the reflector is 120 cm in length having four sockets for four 50-watt lamps situated at the extremeties and in the middle. Generally frosted lamps are used. The horizontal lamp is fixed across the top of the Inspection rack and provided with an independent switch. Recently modifications have been made at the Yokohama Silk Conditioning House using fluroescent tubes for lighting the inspection room.

(6) **Cohesion Tester:**

A Duplon cohesion tester is the standard testing equipment used. It consists of a framework designed for a continuous thread of raw silk (Fig. 45) to be placed in a zig-zag manner between a set of ten hooks on each side of the frame under constant and uniform tension in such a way that the thread can be subjected to a friction action at twenty different places simultaneously and the number of strokes automatically recorded. The total load given for tension is 180 gm.

(7) **Serigraph:**

This is a tensile-strength testing machine with an automatic attachment which records simultaneously the elongation of the thread. The distance between the upper and lower clamps (Fig. 46) is 10 cm and the pulling speed of the lower clamp is 15 cm per minute.

(8) **Conditioning oven:**

This is a chamber with special arrangements for drying raw silk under controlled conditions. It is served by forced ventilation and is capable of drying or desiccation raw silk at 140°C. It is equipped with a balance arranged to weigh the skeins with an accuracy of one centigramme while suspended within the drying chamber. The silk holder is of such type as to ensure free access of the dry air to all skeins.

The eight sets of equipment listed above are the minimum requirements of a silk conditioning and testing house. In addition to these the following equipment are also used for conducting the boil-off and exfoliation tests.

(1) **Boil-off Kettle:**

This is a suitable receptacle for boiling the silk.

(2) **Modified seriplane:**

This is a machine for taking panels for exfoliation tests. The size of the panels is 12 cm high by 8 cm wide. Each frame is of metal and made to hold five panels. The modified seriplane is so constructed that the silk may be reeled on either one or two frames at the same time.

(3) **Platform scale:**

The popular type of platform scale having a capacity of one hundred kilogrammes and a sensitivity of ten grammes is used.

The method and procedure for testing and classification are as per the International Standard method of Raw Silk Testing and Classification officially adopted by the International Silk Association and published by the Japanese Government Silk Conditioning House (see tables).

The Standards and methods of testing and classification though universally accepted in principle and largely followed all over the world, have been slightly modified by countries like India and Italy to suit their special requirements.

In India, with due regard to the pattern of production, the Indian Standards Institution in 1964 recognises three classes, Class I, Class II and Class III, the first two including filature and charka silk respectively and the third raw silk not falling in either of two classes (see tables).

(ii) **Raw Silk Classification**

Article 1. — GRADES

For classification purposes raw silk shall be divided into three categories according to size:

1st. category:	18 denier and below
2nd. category:	19 to 33 denier
3rd. cateogy:	34 denier and above

The grades shall be expressed in the following order in all categories of raw silk 4A, 3A, 2A, A, B.

Article 2. — METHOD OF CLASSIFICATION

The grade of a lot shall be determined in the following manner:

(1) Grading in accordance with the major tests.

The grade of a lot in sizes 33 denier and finer (categories 1 and 2) shall be determined according to the lowest percentage of its size Deviation, Evenness variation 1, Evenness Variation II, Cleanness, Average Neatness and Low Neatness, whereas the grade of a lot in sizes 34 denier and coarser (category 3) shall be determined according to the lowest respective percentage of its Size Deviation, Maximum Deviation, Evenness Variation I, Evenness Variation II, Cleanness, Average Neatness, and Low Neatness, as tabulated in the classification Table for each category.

Should any one or more of these results fall below the limits prescribed for a grade, the lot shall be degraded to the lowest grade wherein such a less or insufficient value is given in the Classification Tables.

(2) De-grading in accordance with the Auxiliary Tests.

a. If any one of the Maximum Deviation, Evenness variation III, Winding, Tenacity, Elongation or Cohesion Tests of a lot in sizes 33 denier and finer, or if any one of the Evenness variation III, Winding, Tenacity or Elongation Tests of a lot in sizes 34 denier and coarser, is found to be lower than the corresponding value listed in the class of auxillary tests, then the grade provisionally established in accordance with the preceding paragraph shall be lowered by as many grades as the difference that exists between the required auxillary test class and the class actually found, provided that any difference more than one class shall be deemed as one class difference with respect to the Maximum Deviation and Evenness Variation III of a lot in sizes 33 denier and finer and Evenness Variation III of a lot in sizes 34 denier and coarser.

In case two or more auxiliary test classes are found to be lower than the corresponding values listed in the classes of the auxiliary tests, then the lot shall be declassed to the lowest auxiliary test class actually found.

(b) In case the result of the Visual Inspection of a lot is found to be "Slightly Inferior" in the general finish and/or the result of the Skein Finish inspection in the Winding Test of a lot is found to be "Poor," the grade of the lot shall be one below that as determined in accordance with the preceding paragraphs.

(c) In case the result of the Visual Inspection of a lot is found to be "Inferior" in its general finish, or in case the number of breaks in the Winding Test exceeds the limits mentioned below the lot shall be determined as B grade.

	Breaks
12 Denier or finer	50
13 to 18 denier	40
19 to 33 denier	35
34 to 69 denier	25
70 denier or coarser	20

(3) **Average Size Variation:**

The conditioned average size of a lot shall not vary more than the following limitations either way from the arithmetical mean of the size limits specified in the contract.

20/22 denier and finer	4% either way
21/23 to 26/28	3.5% either way
27/29 and coarser	Unless by special agreement, the average size shall fall within the size limits specified in the contract.

OUTLINE OF REVISION

1. Evenness test has been revised so that fine or coarse passage be indicated more precisely

The old Evenness test was lenient in the appraisal of the variation intensities of fine or coarse passages.

For example, some panels rated at 80% may have many tolerable variations, while others of the same rating may have detrimental variations, though a few in number. The evenness percentage could not distinguish one from the other. It is clear, however, that the latter is more harmful to raw silk users. In order to rectify this shortcoming, variation intensities of fine or coarse passages are classified into three Evenness Variations: (1) Evenness Variation I, (2) Evenness Variation II, and (3) Evenness Variation III. The limit of total number of set for each grade or class of three variations is shown in Classification Tables.

This method is based on the same idea as the proposed testing of raw silk by electronic devices, and also conforms to the recommendation that shorter sizing skeins be adopted.

2. **Winding test has been largely improved**

With a view to more precisely revealing the quality of raw silk that strongly affects the winding efficiency in the mill, the old Breaking Test has been more rationally improved and Skein-finish Inspection has been newly introduced.

(i) **Breaking test has been revised to show the actual state of winding of raw silk**

The old Breaking Test performed preliminary winding, in which breaks in the outermost surface of skein were not checked. But raw silk users wind silk from the outermost surface of skeins, where many breaks occur. There was a wide difference between the test and the actual usage in the mill. In order to fill the gap, in the case where skeins are wound from the outer surface, the preliminary winding has been incorporated into the main test.

(ii) **To reveal winding efficiency, skein-finish inspection has been introduced**

Winding efficiency is affected by ease in handling of skeins, which depends on the finish and make-up of skeins. So, in addition to the Breaking Test the degree of trouble in the winding operations is now checked. Since the result cannot be determined before skeins are put under the winding operation, the kind and the degree of trouble which takes place during winding operations in Breaking test are inspected and penalized according to prescribed rates. The lot is classified by the total of penalties.

By this method, the quality affecting winding efficiency is revealed more clearly and precisely.

3. **Visual inspection of entire lot has been rationalised**

With the introduction of Skein-finish Inspection into the Winding Test, the overlapping items of Visual Inspection have been deleted, and the Uniformity Test and General Finish test have been unified into the General Finish Test in visual inspection of the entire lot.

4. **In classification tables, those items affecting fabric qualities and processing efficiency have been stressed rather than evenness.**

Under the old Classification Table, a lot was graded mainly by Evenness Test results, while other important items for processing silk were comparatively undervalued. Also, the grade intervals were too narrow in the light of the actual requirements of raw silk. Further more, in Size deviation Test and Maximum Deviation Test, the results of which change according to the size, the limit of a grade became more lenient as the size increased.

A comparison of the new 2A grade of 20/22 denier with the old 2A grade, shows that each of the grade limits in items important to silk users, such as Size Deviation, Maximum Deviation, Cleanness, Winding, Tenacity and Cohesion, has become stricter. In Size Deviation, for instance, the grade limit of the new 4A is identical with that for the old 6A, and the grade limit of the new 3A with that of the old 4A.

Under the new method, in addition, the same degree of strictness of the grade limit as 20/22 denier is applied to all other sizes.

Under the new Classification, the highest grade is 4A and the lowest, B grade.

Chapter 9

WILD SILK REELING

Tasar, Muga and Eri are the commercially important varieties among the wild silks. Of these, Tasar is the most popular and is produced in China, India and Japan. The Indian Tasar worm feeds on **asan** (*Terminalia tomentosa*), **arjun** (*Terminalia arjun*) and **sal** (*Shorea robusta*) while the Chinese and Japanese worms feed on **oak** (*Quercus sp.*). Muga silk is exclusively a product of Assam in India. The worm is polyphagus and thrives mostly on plants of the lauraceae family, e.g. **som** (*Machilus Bombycina*), **soalu** (*Litsea polyantha*), **mejankari** (*Litsea citrata*) and **bajori** (*Ziziphus jujuba*). Eri is also producedin India and to a lesser extent in some parts of Burma and Africa. The main food plant of Eri is **castor** (*Ricinus communis*).

Tasar: The tasar cocoon unlike the cocoon of *Bombyx mori* is very large, measuring about 5 x 3 cm and is generally oval in shape. It is clear in outline without prominent floss. It may be of various shades of colour, yellow, cream, grey, pink or brown, etc. The cocoons have hard and long peduncles with a ring at the end. The weight of cocoon varies from 7 gm to 14 gm according to variety, season, food plant, etc. (fig. 47).

The cocoon has three distinctive layers made up of continuous filament. the first two outer layers are firmly cemented into a hard shell while the innermost layer is thin and surrounds the chrysalis. The intricate winding of the filament is held securely by the presence of sericin which later gets discharged into the cocoon boiling process preliminary to reeling.

The cocoon bave varies in length from 800m to 1500m and likewise the denier also varies from 5 to 13D depending on the season, variety and food plants, as well as the locality of production. The shape of the bave in its cross section is flat like a ribbon, unlike that of *Bombyx mori* which is circular or oval. The bave is coarse and stiff and the diminution in denier of filament, from the outer to inner layers, is conspicuous. The bave is comparatively loosely striated and contains irregularly placed vacuoles. The colour of the bave is deeply ingrained and ranges from light to deep brown.

It is less reactive in general towards chemical re-agents and is therefore difficult to bleach and dye. It requires a severe treatment for degumming. it is seriously affected by an alkaline solution of copper hydrate in glycerol. It is almost entirely unaffected by concentrated hydrochloric acid, chromic acid and zinc chloride which dissolves mulberry silk. Soda ash and soap both followed by hydrogen peroxide partly bleach it and reduce the lustre. Hydrogen peroxide and sodium silicate preserve the colour.

The cocoons are stifled by boiling them in water for half an hour and drying them in the sun. This effectively kills and dries the pupae and enables prolonged storage.

The cocoons require to be softened and the filaments loosened before reeling. This is an elaborate and extended process consisting of pre soaking of cocoons in an alkaline bath and later steam-cooking for several hours. In spite of this treatment all the cocoons are not uniformly cooked and the undercooked ones may require further cooking.

While the above is the primitive system, efforts are being made to systematise cooking by using steam pressure chambers.

The outer layer with the peduncle is carefully peeled off and the inner cocoon shell is taken for reeling.

Filaments from 5 - 6 cocoons are drawn and reeled into a twisted thread. The wet cocoons are placed on wet cloth and the filaments are passed through a thread guide and over a roller before the end is passed through the twisting mechanism and attached to the bobbin. When the machine is in operation, the roller draws the filaments from the several cocoons in the end, and feeds the grouped filaments to the twister before the twisted thread is wound on the bobbin. Twisting of the the Tasar silk is necessary to hold together the several component filaments. A simple distributor mechanism distributes the wound thread uniformly on the bobbin. The threads so produced are transferred to standard reels by re-reeling. Generally four ends are reeled by a reeler, and about 700 cocoons are utilised for producing about 250 gm of reeled yarn per day.

In the primitive system, the method of producing the thread is similar to that described above. The only difference between the primitive and improved system lies in the method of twisting. Instead of using an elaborate reeling appliance with a twisting mechanism as in the improved machine, a simple frap reel (Natwa) is used for winding the thread, and the twist is imparted by the operator rubbing the filaments on the thigh several times in their passage from the cocoons to the Natwa. This process is laborious and difficult and enables production of only about 50–60 gm of reeled yarn per day from about 120–150 cocoons. Thus, whether the reeling is done by the primitive method or the improved method, the production is limited. Furthemore, the quality lacks standardization. Due to the mechanical advantages provided in the modern machine the reeled silk will be more uniform in size and twists. The reeled Tasar silk, whether on modern machines or by primitive methods is brownish in colour and harsh to feel. In terms of yield of reeled yarn it is hardly 30 per cent of the weight and length of the total silk content of the cocoon. The remaining unreeled silk is the by-product, and is used for producing a coarse variety of handloom yarn.

Muga: The cocoon is golden or light brown in appearance, 4.5 to 6 cm long by 2.2 to 2.7 cm broad with a rudimentary peduncle. Worms which feed on mejankari and chapa (*Magnolia sphenocarpa*) yield cocoons which are whitish and more glossy, but gradually turn golden when dry. Double cocoons are rare and found only when the cocoonage is unsuitable. The outer surface of the cocoon is slightly flossy, and this can be easily removed by brushing. The inner middle portion contains the main silk which is reelable. The portion next to pupae is unreelable as it is too flimsy. Each cocoon is composed of a single continuous filament of about 350–400 m in length and a denier of 4.5 which gradually diminishes in size towards the innermost layer of the cocoon shell. The fibre is round like mulberry silk. The filament has high tensile strength (Fig.49).

Reeling cocoons are stifled by exposing them to hot air, followed by sundrying. The ccoons are sorted into good and filmsy, before reeling. Pierced cocoons and the silk wastes from reeling are used for spinning.

Reeling of Muga is simple, though cooking is elaborate. Cooking is done in boiling alkaline solution for about one hour for removing the natural gum which binds the filament in the cocoon. Sometimes two to three hours of cooking are required for easy reeling. Some reelers also use mucilaginous material obtained from the fruit of *Dillenia indica*, bark of *Bombax malabaricum* and leaves of *Malva arvensis*, to facilitate easy unwinding and to reduce friction on the reeler's hand at the time of twisting the thread.

The cooked cocoons are reeled in tepid water heated over a slow fire. The true end of the filament is found and a number of filaments from as many as 7 to 20 cocoons are rolled together between the palm of the right hand across the thigh, while the left hand works the roller for winding the yarn.

A slightly improved method of reeling consists in using equipment known locally as 'Bhir'. This equipment consists essentially of a basin to serve as a water bath for the cocoons and a roller with a large wheel at one end for frapping. Reeling is done in the same way as described earlier but twisting is done by rubbing between the fingers. In another type, the roller is provided with a foot treadle for turning it. There is also a new machine which is provided with a bobbin and spinning mechanism for imparting the twists to the reeled yarn. The average production of raw silk is about 250 gm from 1000 Muga cocoons.

The reeled silk is shimmering gold in colour and is permanent. The silk yielded by worms fed on **mejankari** and **chapa** trees, however, yield whiter silk of a very fine quality.

Eri: This worm spins open-mouthed cocoons and the filament is not continuous. Therefore, the Eri cocoons can only be spun and not reeled. The adult moths are allowed to emerge and only the pierced cocoons are used, for spinning purposes (Fig. 50).

The cocoons are at first boiled in an alkaline solution containing soap and soda, with the object of removing the gum. Otherwise spinning is not possible. This is done by loosely wrapping the cocoons in a piece of cloth, and dipping them into the vessel containing the solution. When the cocoons have been sufficiently boiled, they are taken out and washed in cold water several times to remove the solvent. The cocoons are then squeezed until a large part of the water is removed before being spread out and dried. The cocoons thus prepared are ready for spinning.

The appliances commonly used for spinning are **takli** and the common charka used for spinning cotton. Recently an improved equipment with treadle mechanism and automatic traverse motion has been developed, and is used for spinning. The advantage is that feeding of fibres can be controlled with great ease and silk distributed on the bobbin more evenly. Hence better quality yarn and increased output is possible. About 20–30 gm of yarn can be spun per day on the treadle and charka appliances. Production on taklis is far less. The Eri spun yarn is white and lustrous and on an average the yield of yarn is about 50–60 per cent of the weight of the cocoons. As most of the silk is spun into yarn, there is hardly any waste.

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Classification Table for Raw Silk of Category I
(18 denier and finer)

GRADE / MAJOR TESTS	6A	5A	4A	3A	2A	A	B	C	D
Size 12 d. and below	0.80	0.85	0.05	1.05	1.15	1.25	1.35	1.50	above 1.50
Deviation 13d. — 15 d.	0.90	0.95	1.05	1.15	1.25	1.35	1.50	1.70	" 1.70
(denier) 16d.-18d.	1.05	1.15	1.25	1.35	1.45	1.60	1.75	1.95	" 1.95
Average Evenness (%)	94	93	91	89	86	84	82	80	below 80
Low Evenness (%)	87	85	83	80	77	75	73	70	" 70
Clearness (%)	96	95	94	93	92	90	88	85	" 85
Average Neatness (%)	95	94	93	92	90	88	86	84	" 84
Low Neatness (%)	92	90	88	86	83	79	75	70	" 70

CLASS / AUXILLARY TEST	(I)	(II)	(III)	(IV)	(V)	(VI)	(VII)	(VIII)	(IX)
Maximum 12d. and below	2.1	2.3	2.5	2.7	3.0	3.3	3.6	4.0	above 4.0
Deviation 13d.-15d.	2.4	2.5	2.7	3.0	3.3	3.6	4.0	4.5	" 4.5
(Denier) 16d.-18d.	2.8	3.0	3.3	3.6	3.9	4.2	4.6	5.2	" 5.2

CLASS / AUXILLARY TEST	(I)	(II)	(III)	(IV)
Winding 12d. and below	10	15	23	above 23
(breaks) 13d. 18d.	7	12	20	" 20

CLASS / AUXILLARY TESTS	(I)	(II)	(III)
Tenacity (grams)	3.7	3.6	below 3.6
Elongation (%)	19	18	" 18
Cohesion (strokes) 13d. 18d.	40	35	" 35

CLASS / AUXILLARY TEST	(I)	(II)
Cohesion (strokes) 12 d. and below	30	below 30

Classification Table for Raw Silk of Category II
(19 denier–33 denier)

GRADE / MAJOR TESTS	6A	5A	4A	3A	2A	A	B	C	D	E
Size 19d.–22d.	1.15	1.25	1.35	1.50	1.65	1.80	1.95	2.15	2.40	above 2.40
Deviation 23d.–27d.	1.40	1.50	1.65	1.80	1.95	2.10	2.30	2.50	2.70	" 2.70
(Denier) 28 d.–33d.	1.60	1.75	1.90	2.10	2.30	2.50	2.70	2.95	3.20	" 3.20
Average Evenness (%)	94	93	91	89	86	84	82	80	77	below 77
Low Evenness (%)	87	85	83	80	77	75	73	70	66	" 66
Cleanness (%)	96	95	94	93	92	90	88	85	81	" 81
Average Neatness (%)	95	94	93	92	90	88	86	84	82	" 82
Low Neatness (%)	92	90	88	86	83	79	75	70	64	" 64
CLASS / AUXILLARY TEST	(I)	(II)	(III)	(IV)	(V)	(VI)	(VII)	(VIII)	(IX)	(X)
Maximum 19d.–22d.	3.0	3.3	3.6	4.0	4.4	4.8	5.2	5.7	6.4	above 6.4
Deviation 23d.–27d.	3.8	4.1	4.4	4.8	5.2	5.7	6.2	6.8	7.4	" 7.4
(denier) 28d.–33d.	4.3	4.7	5.2	5.7	6.2	6.7	7.3	8.0	8.7	" 8.7

CLASS / AUXILLARY TEST	(I)	(II)	(III)	(IV)	(V)
Winding (breaks)	6	10	15	20	above 20

CLASS / AUXILLARY TESTS	(I)	(II)	(III)
Tenacity (grams)	3.7	3.6	below 3.6
Elongation (%)	19	18	" 18
Cohesion (strokes)	60	50	" 50

Classification Table for Raw Silk of Category III
(34 denier and coarser)

MAJOR TESTS / GRADE	4A	3A	2A	A	B	C	D	E
Size 34d.–49d.	3.10	3.50	3.90	4.40	5.00	5.90	7.00	above 7.00
Deviation 50d.–69d.	4.10	4.60	5.20	5.80	6.70	7.90	9.30	" 9.30
(denier) 70d. and above	5.10	5.70	6.30	7.10	8.20	9.70	11.40	" 11.40
Maximum 34d.–49d.	9.0	10.0	11.0	13.0	15.0	18.0	21.0	" 21.0
Deviation 50d.–69d.	12.0	14.0	16.0	18.0	21.0	24.0	28.0	" 28.0
(denier) 70d. and above	15.0	17.0	19.0	22.0	25.0	29.0	34.0	" 34.0
Average Evenness (%)	91	89	86.	84	82	80	77	below 77
Low Evenness (%)	83	80	77	75	73	70	66	" 66
Cleanness (%)	94	92	90	87	83	79	75	" 75
Average Neatness (%)	93	91	89	87	84	81	78	" 78
Low Neatness (%)	87	85	82	78	74	68	62	" 62

AUXILLARY TEST / CLASS	(I)	(II)	(III)	(IV)	(V)
Winding 34d.–69d.	3	6	10	15	above 15
(breaks) 70d. and above	2	4	6	10	" 10

AUXILLARY TESTS / CLASS	(I)	(II)	(III)
Tenacity (grams)	3.7	3.6	below 3.6
Elongation(%)	19	18	" 18

Revised Classification Table for Raw Silk of Category I (18 denier and finer)

ITEMS	GRADE	4A	3A	2A	A	B
Size	12d. and below	0.80	0.95	1.10	1.35	above 1.35
Deviation	13d. – 15d.	0.90	1.05	1.25	1.50	" 1.50
(denier)	16d. – 18d.	1.00	1.20	1.40	1.70	" 1.70
Evenness Variation I (Count)		150	170	190	210	" 210
Evenness Variation II (Count)		10	17	26	37	" 37
Cleanness (%)		97	95	93	88	below 88
Average Neatness (%)		94	92	90	87	" 87
Low Neatness (%)		90	87	83	77	" 77

ITEMS	CLASS	(1)	(2)	(3)	(4)	(5)
Maximum Deviation	12d. and below	2.2	2.6	3.0	3.6	above 3.6
	13d. – 15d.	2.4	2.8	3.3	4.1	" 4.1
(denier)	16d. – 18d.	2.7	3.2	3.8	4.6	" 4.6
Evenness Variation III (Count)		0	1	2	6	" 6

ITEM	CLASS	(1)	(2)	(3)	(4)
Winding (breaks)	12d. and below	7	15	25	above 25
	13d. – 18d.	5	12	21	" 21

ITEMS	CLASS	(1)	(2)
Tenacity (grams)		3.7	below 3.7
Elongation (%)		18	" 18
Cohesion (strokes)		40	" 40

Revised Classification Table for Raw Silk of Category II
(19 denier — 33 denier)

ITEMS	GRADE	4A	3A	2A	A	B
Size	19 d. – 22 d.	1.15	1.35	1.60	1.95	above 1.95
Deviation	23 d. – 25 d.	1.30	1.50	1.80	2.20	" 2.20
(denier)	26 d. – 29 d.	1.40	1.65	1.95	2.35	" 2.35
	30 d. – 33 d.	1.50	1.75	2.05	2.50	" 2.50
Evenness Variation I (Count)		150	170	190	210	" 210
Evenness Variation II (Count)		10	17	26	37	" 37
Cleanness (%)		97	95	93	88	below 88
Average Neatness (%)		94	92	90	87	below 87
Low Neatness (%)		90	87	83	77	below 77

ITEMS	CLASS	(1)	(2)	(3)	(4)	(5)
Maximum	19 d. – 22 d.	3.1	3.6	4.3	5.3	above 5.3
Deviation	23 d. – 25 d.	3.5	4.1	4.9	5.9	" 5.9
(denier)	26 d. – 29 d.	3.8	4.5	5.3	6.3	" 6.3
	30 d. – 33 d.	4.0	4.7	5.5	6.8	" 6.8
Evenness Variation III (Count)		0	1	2	6	" 6

ITEM	CLASS	(1)	(2)	(3)	(4)
Winding (breaks)		4	10	18	above 18

ITEMS	CLASS	(1)	(2)
Tenacity (grams)		3.7	below 3.7
Elongation (%)		18	below 18
Cohesion (strokes)		60	below 60

Revised Classification Table for Raw Silk of Category III
(34 denier and coarser)

ITEMS	GRADE	4A	3A	2A	A	B
Size	34d. 49d.	2.60	3.10	3.65	4.45	above 4.45
Deviation	50d. 69d.	3.75	4.40	5.2	6.35	" 6.35
(denier)	70d. and above	4.45	5.25	6.2	7.60	" 7.60
Maximum	34d. 49d.	8.0	9.5	11.0	13.5	" 13.5
Deviation	50d. 69d.	11.0	13.0	15.5	19.0	" 19.0
(denier)	70d. and above	13.5	16.0	18.5	23.0	" 23.0
Evenness Variation I (count)		150	170	190	210	" 210
Evenness Variation II (count)		10	17	26	37	" 37
Cleanness (%)		97	95	93	88	below 88
Average Neatness (%)		94	92	90	87	" 87
Low Neatness (%)		90	87	83	77	" 77

ITEM	CLASS	(1)	(2)	(3)	(4)	(5)
Evenness Variation III (count)		0	1	2	6	above 6

ITEM	CLASS	(1)		(2)	(3)	(4)
Winding 34 d.– 69 d.		1		6	13	above 13
(breaks) 70d. and above		0		4	10	" 10

ITEMS	CLASS	(1)		(2)
Tenacity (grams)		3.7		below 3.7
Elongation (%)		18		" 18

Classification of Raw Silk — Indian Standards — Class I Raw Silk (3.8 tex (or 34 denier) and Above)

Major Tests / Grade	4A	3A	2A	A	B	C	D	E
Size deviation, tex (or denier)								
3.8 to 5.4 tex (or 34 to 49 d.)	0.344 (3.10)	0.389 (3.50)	0.433 (3.90)	0.489 (4.40)	0.556 (5.00)	0.656 (5.90)	0.778 (7.00)	Above 0.778 (" 7.00)
5.6 to 7.7 tex (or 50 to 69 d)	0.456 (4.10)	0.511 (4.60)	0.578 (5.20)	0.644 (5.80)	0.744 (6.70)	0.878 (7.90)	1.033 (9.30)	(" 1.033) (" 9.30)
7.8 tex (or 70 d) and above.	0.567 (5.10)	0.633 (5.70)	0.700 (6.30)	0.789 (7.10)	0.911 (8.20)	1.078 (9.70)	1.267 (11.40)	" 1.267 (" 11.40)
Maximum deviation, tex (or denier)								
3.8 to 5.4 tex (or 34 to 49 d)	1.00 (9.0)	1.11 (10.0)	1.22 (11.0)	1.44 (13.0)	1.67 (15.0)	2.00 (18.0)	2.33 (21.0)	Above 2.33 (" 21.0)
5.6 to 7.7 tex (or 50 to 69 d)	1.33 (12.0)	1.56 (14.0)	1.78 (16.0)	2.00 (18.0)	2.33 (21.0)	2.67 (24.0)	3.11 (28.0)	" 3.11 (" 28.0)
7.8 tex (or 70 d) and above	1.67 (15.0)	1.89 (17.0)	2.11 (19.0)	2.44 (22.0)	2.78 (25.0)	3.22 (29.0)	3.78 (34.0)	" 3.78 (" 34.0)
Evenness, percent	91	89	86	84	82	80	77	Below 77
Low evenness, percent	83	80	77	75	73	70	66	Below 66
Cleanness, percent	94	92	90	87	83	79	75	Below 75
Neatness, percent	93	91	89	87	84	81	78	Below 78
Low neatness, percent	87	85	82	78	74	68	62	Below 62

Auxillary Test / Grade	(I)	(II)	(III)	(IV)	(V)
Winding (breaks)					
3.8 to 7.7 tex (or 34 to 69 d)	3	6	10 15		Above 15
7.8 tex (or 70 d) and above	2	4	6 10		" 10

Auxillary Tests / Grade	(I)	(II)	(III)
Tenacity g/tex	33 (3.7)	32 (3.6)	Below 32 (" 3.6)
Elongation, percent	19	18	Below 18

Classification of Raw Silk — Indian Standards — Class II
Raw Silk

Grade / Major Tests	1	2	3	4	5	6	7
Composite, percent							
1.9 tex (or 17 d) or below	84	81	76	72	66	60	Below 60
2.0 tex (or 18 d) or above	83	80	76	71	65	59	" 59
Evenness, percent	84	80	76	71	65	59	Below 59
Low evenness, percent	75	70	66	60	53	47	Below 47
Cleanness, percent							
1.9 tex (or 17 d) or below	88	84	79	74	68	62	Below 62
2.0 tex (or 18 d) or above	85	81	76	70	64	57	" 57
Neatness, percent	85	80	75	70	65	60	Below 60

Grade / Auxillary Tests	(I)	(II)	(III)	(IV)	(V)
Size deviation, tex (or denier)					
1.7 tex (or 15 d) or below	0.167(1.50)	0.180(1.62)	0.194(1.75)	Above 0.194 (Above 1.75)	
1.8 to 2.0 tex (or 16 to 18d)	0.194(1.75)	0.208(1.88)	0.222(2.00)	" 0.222 (" 2.00)	
2.1 to 2.4 tex (or 19 to 22d)	0.222(2.00)	0.236(2.12)	0.264(2.38)	" 0.264 (" 2.38)	
2.6 to 3.0 tex (or 23 to 27 d)	0.250(2.25)	0.278(2.50)	0.306(2.75)	" 0.306 (" 2.75)	
3.1 tex (or 28 d) or above	0.306(2.75)	0.333(3.00)	0.361(3.25)	" 0.361 (" 3.25)	
Maximum deviation, tex (or denier)					
1.7 tex (or 15 d) or below	0.51(4.6)	0.56(5.0)	0.61(5.5)	Above 0.61 (above 5.5)	
1.8 to 2.0 tex (or 16 to 18 d)	0.74(6.7)	0.76(6.8)	0.78(7.0)	" 0.78 (" 7.0)	
2.1 to 2.4 tex (or 19 to 22d)	0.76(6.8)	0.87(7.8)	1.00(9.0)	" 1.00 (" 9.0)	
2.6 to 3.0 tex (or 23 to 27 d)	0.91(8.2)	1.06(9.5)	1.22(11.0)	" 1.22 (" 11.0)	
3.1 tex (or 28 d) or above	1.08(9.7)	1.22(11.0)	1.44(13.0)	" 1.44 (" 13.0)	
Winding (breaks)					
1.9 tex (or 17 d) or below	80	100	140	Above 140	Above 180
2.0 tex (or 18 d) or above	60	80	110	" 110	" 160

Grade / Auxillary Tests	(I)	(II)	(III)	IV)
Tenacity g/tex (or g/denier)				
1.9 tex (or 17 d) or below	31(3.4)	29(3.2)	27(3.0)	Below 27 (Below 3.0)
2.0 tex (or 18 d) or above	31(3.4)	29(3.2)	27(3.0)	" 27 (" 3.0)
Elongation, percent				
1.9 tex (or 17 d) or below	18.0	17.0	15.0	" 15.0
2.0 tex (or 18 d) or above	18.0	17.0	16.0	" 16.0

Grade / Auxillary Test	(I)	(II)	(III)
Cohesion (strokes)			
1.9 tex (or 17 d) or below	30	20	Below 20
2.0 tex (or 18 d) or above	50	30	" 30

Classification of Raw Silk — Indian Standards — Class III Raw Silk

Major Test \ Grade	8	9	10	11	12	13	14
Cleanness, percent							
1.9 tex (or 17 d) or below	88	84	79	74	68	62	Below 62
2.0 tex (or 18 d) or above	85	81	76	70	64	57	" 57

Auxillary Tests \ Grade	(I)	(II)	(III)	(IV)	(V)
Size deviation, tex (or denier)					
1.7 tex (or 15 d) or below	0.167	0.180	0.194	Above 0.194	
1.7 tex (or 15 d) or below	(1.50)	(1.62)	(1.75)	(" 1.75)	
1.8 to 2.0 tex (or 16 to 18 d)	0.194	0.208	0.222	" 0.222	
	(1.75)	(1.88)	(2.00)	(" 2.00)	
2.1 to 2.4 tex (or 19 to 22 d)	0.222	0.236	0.264	" 0.264	
	(2.0)	(2.12)	(2.38)	(" 2.38)	
2.6 to 3.0 tex (or 23 to 27d)	0.250	0.278	0.306	" 0.306	
	(2.25)	(2.50)	(2.75)	(" 2.75)	
3.1 tex (or 28 d) or above	0.306	0.333	0.361	" 0.361	
Winding (breaks)	(2.75)	(3.00)	(3.25)	(" 3.25)	
1.9 tex (or 17 d) or below	80	100	140	" 140	Above 180
2.0 tex (or 18 d) or above	60	80	110	" 110	" 160

Auxillary Tests \ Grade	(I)	(II)	(III)	(IV)
Tenacity g/tex (or g/denier)				
1.9 tex (or 17 d) or below	27	25	23	Below 23
	(3.0)	(2.8)	(2.6)	(" 2.6)
2.0 tex (or 18 d) or above	27	25	23	" 23
	(3.0)	(2.8)	(2.6)	(" 2.6)
Elongation, percent.				
1.9 tex (or 17 d) or below	18.0	17.0	15.0	" 15.0
2.0 tex (or 18 d) or above	18.0	17.0	15.0	" 15.0

Auxillary Test \ Grade	(I)	(II)	(III)
Cohesion (strokes)			
1.9 tex (or 17 d) or below	80	20	Below 20
2.0 tex (or 18 d) or above	50	30	" 30

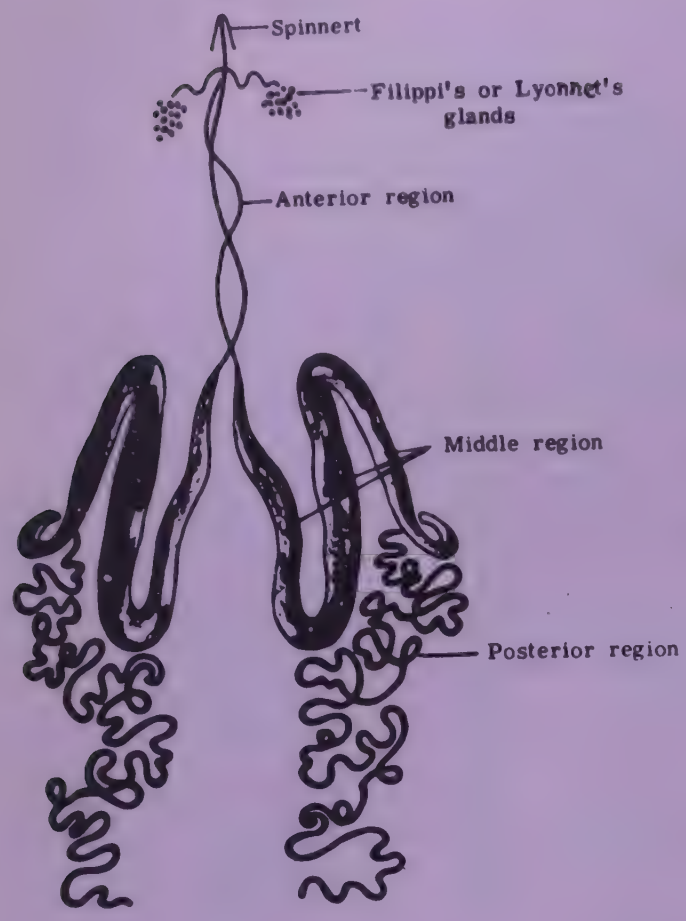


Fig. 1 — Silk gland of Silkworms

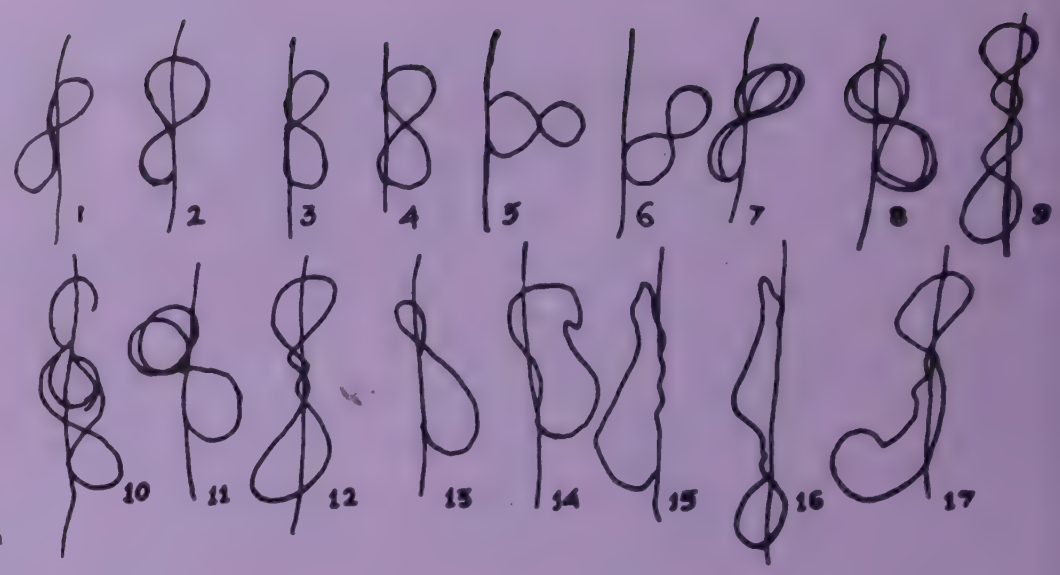


Fig. 2 — Different types of loop formation in the cocoon shell

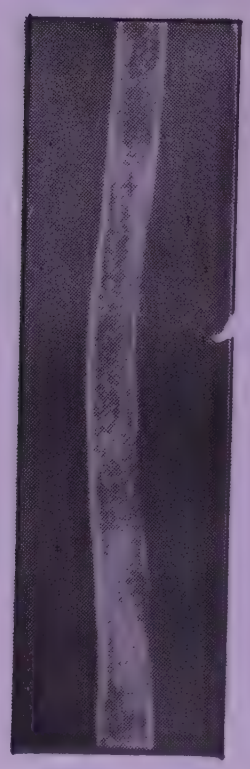


Fig. 3 — Nature of raw silk bave

Fig. 4 —Degummed silk bave

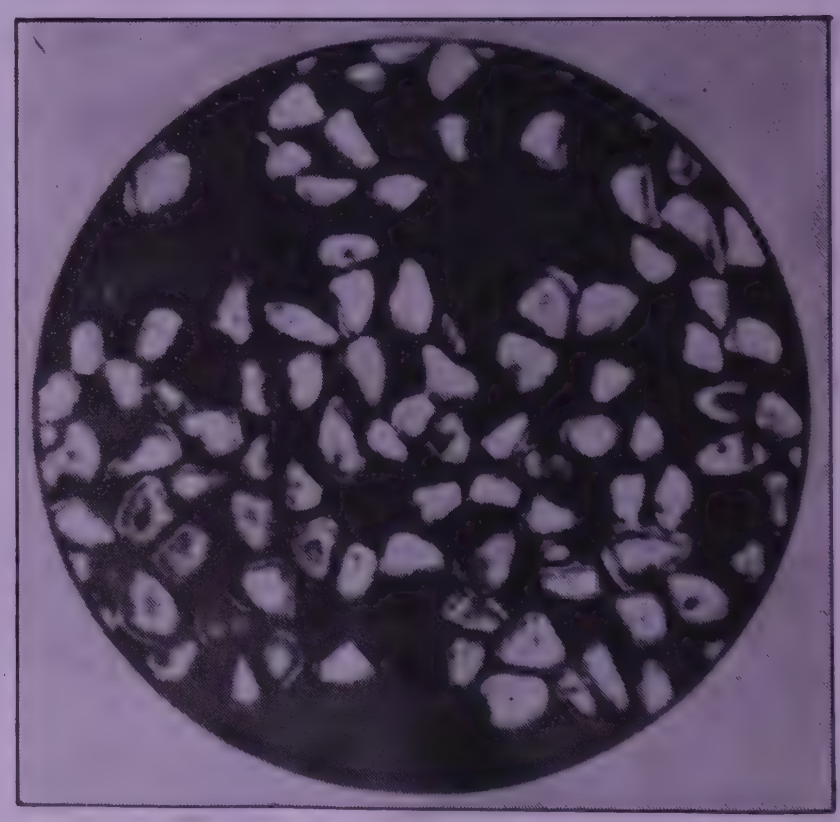


Fig. 5 — Cross-section of degummed brins

Fig. 6 — Basket-steaming of cocoons

Fig. 7 — Filature method of steam-stifling

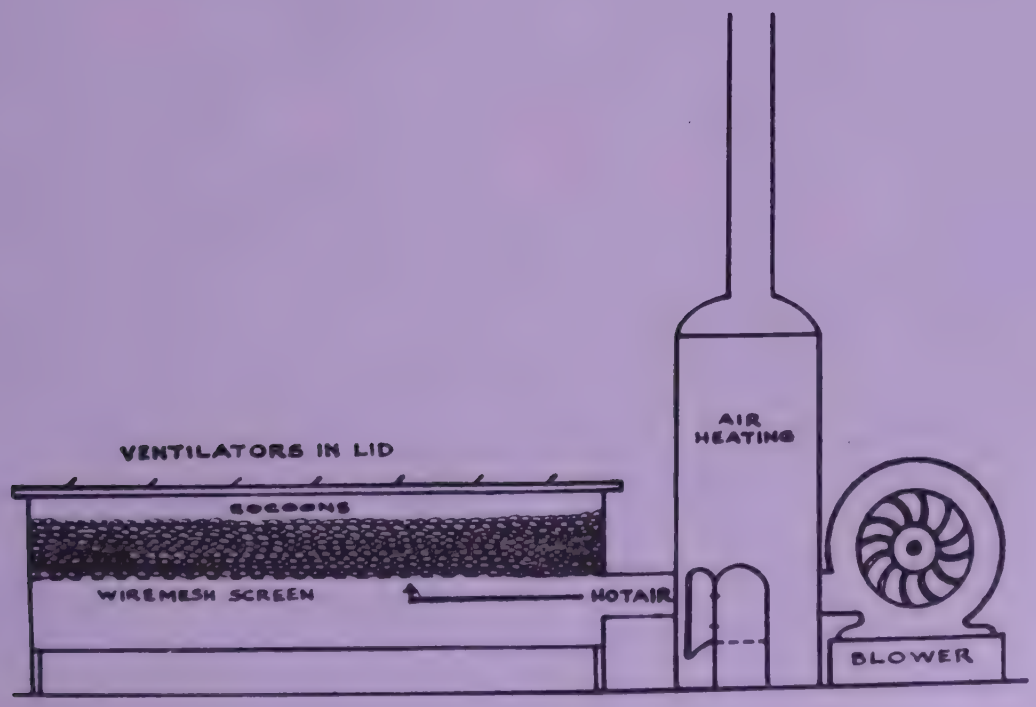


Fig. 8 — Old method cocoon drying equipment

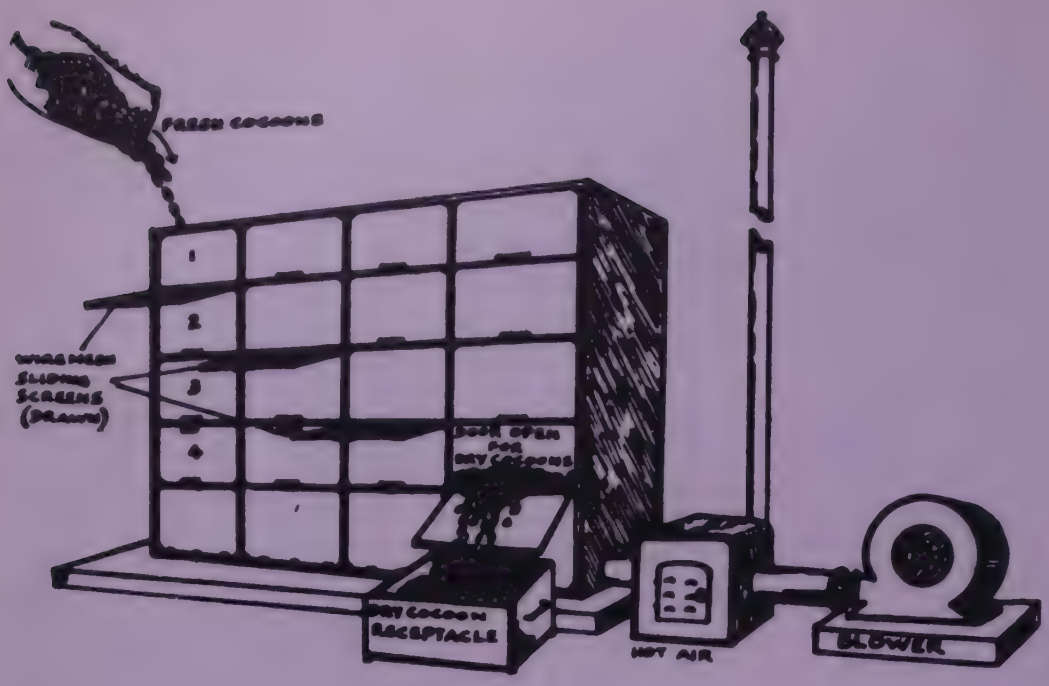


Fig. 9 — Cocoon drying chambers (vertical type)

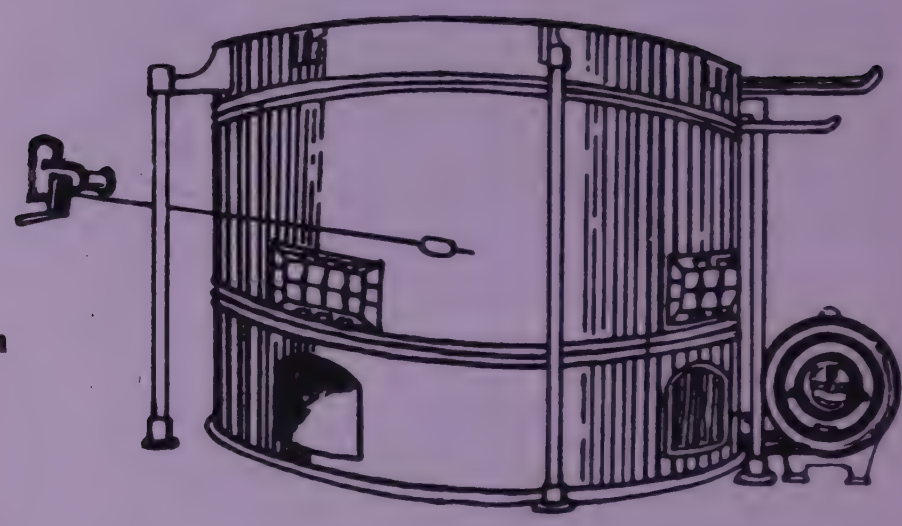


Fig. 10 — Cocoon desiccator with rotating drum

Fig. 11 — "Yamoto" hot air drying machine

1.Blower 2. Heater 3. Hot Air Duct into Chamber 4. Air Exhaust from chamber 5. Air inlet 6. Conveyer 7. Automatic cocoon feeder 8. Exhaust fan 9. Screen type cocoon conveyer 10. Chamber partition board 11. Cocoon cooler 12. Thermo indicator

Fig. 12 — Sorting and deflossing of cocoons (Mysore)

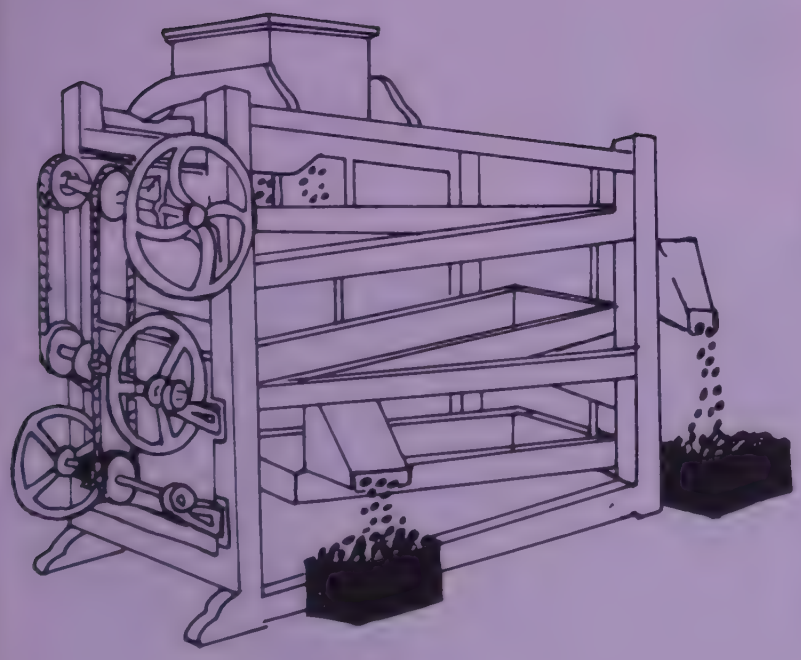


Fig. 13 — Cocoon riddling machine (simple type)

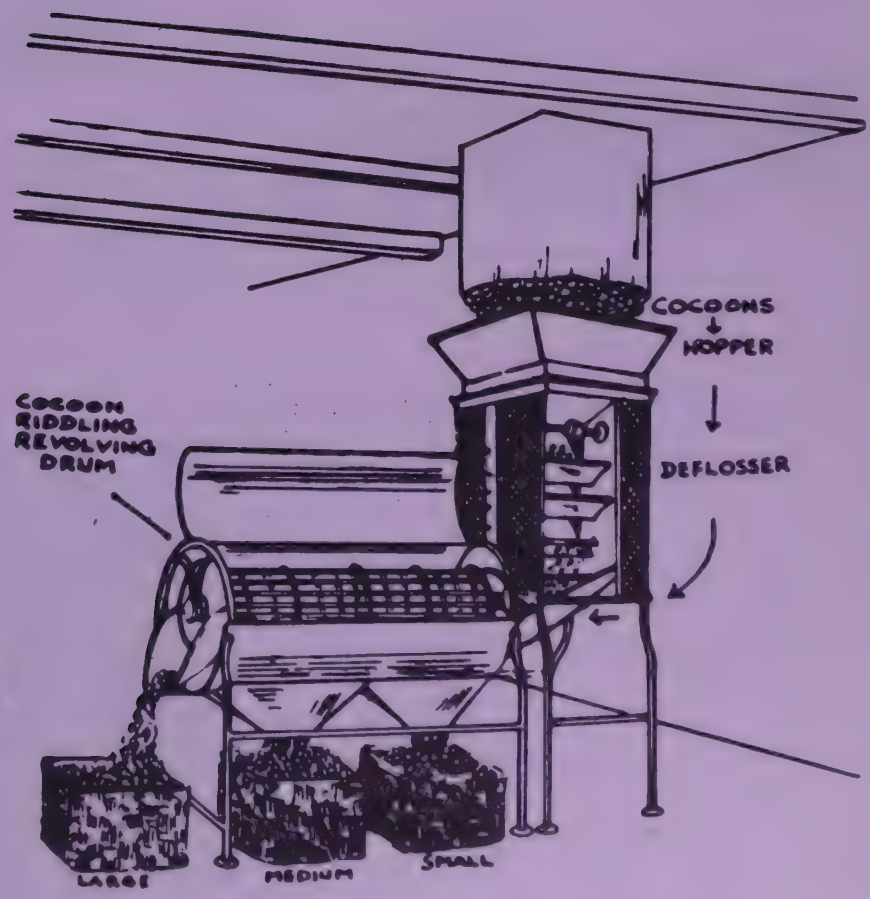


Fig. 14 — Combined cocoon deflossing and riddling machine

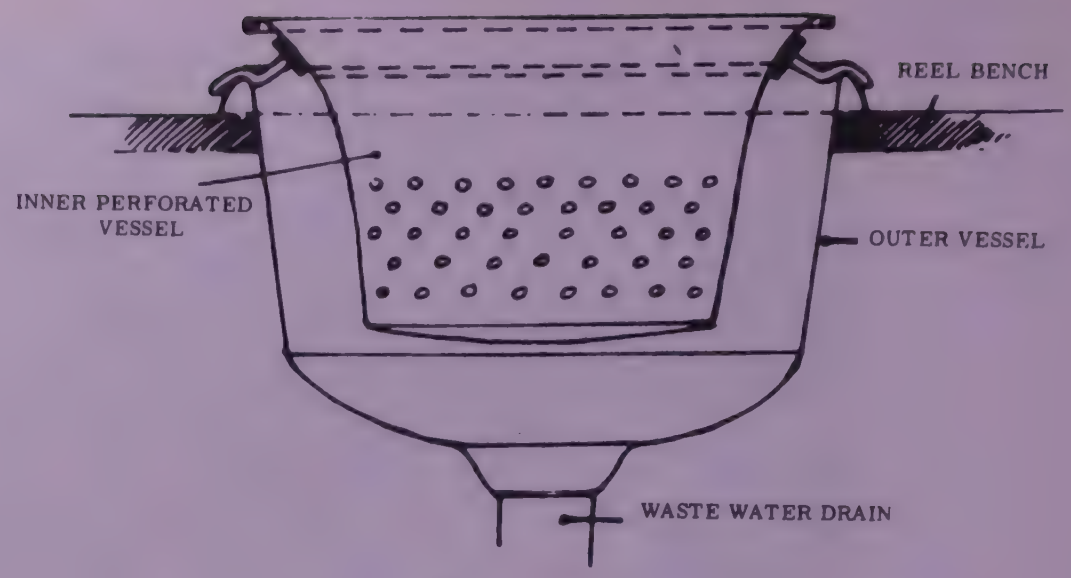


Fig. 15 — Open pan filature cooking basin

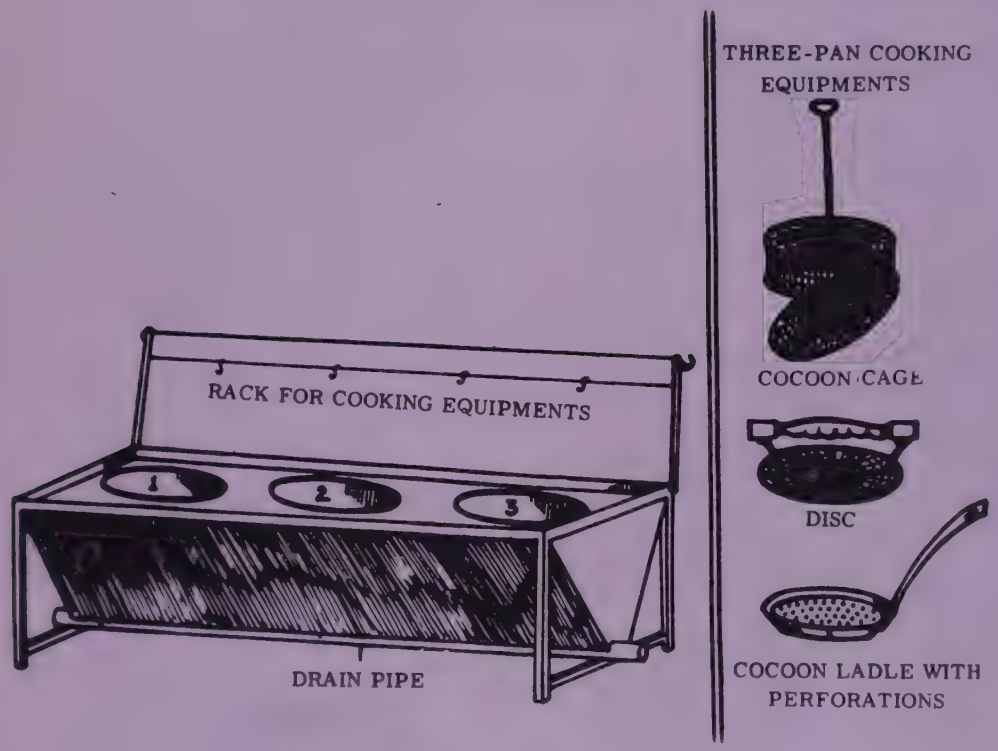


Fig. 16 — Three-pan type cooking unit

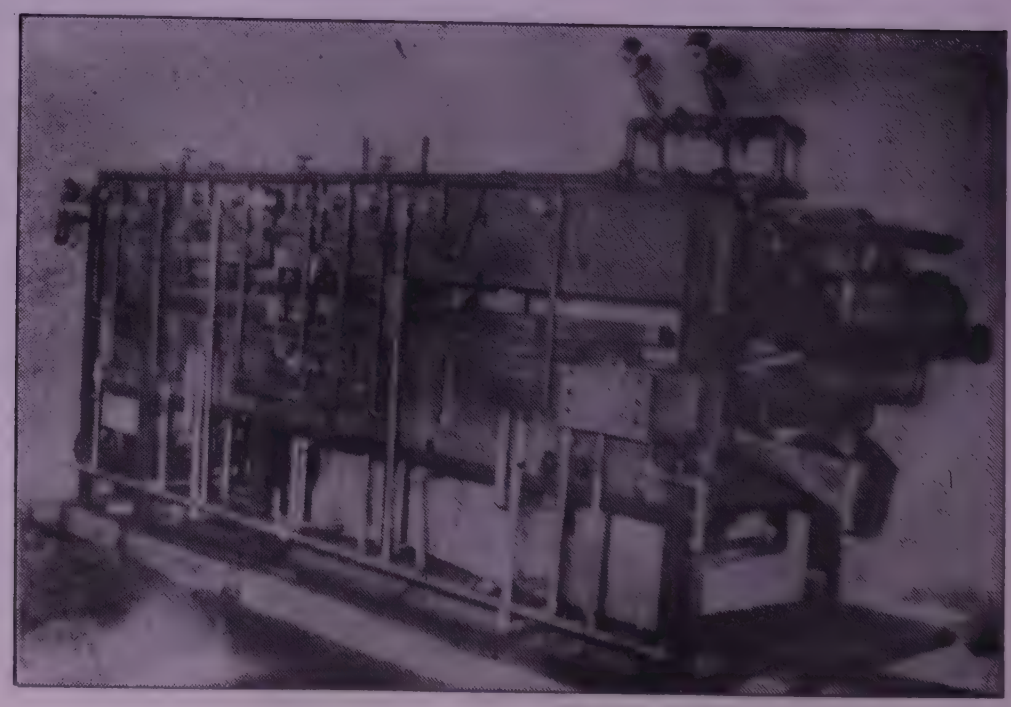


Fig. 17 — Central cocoon boiling machine

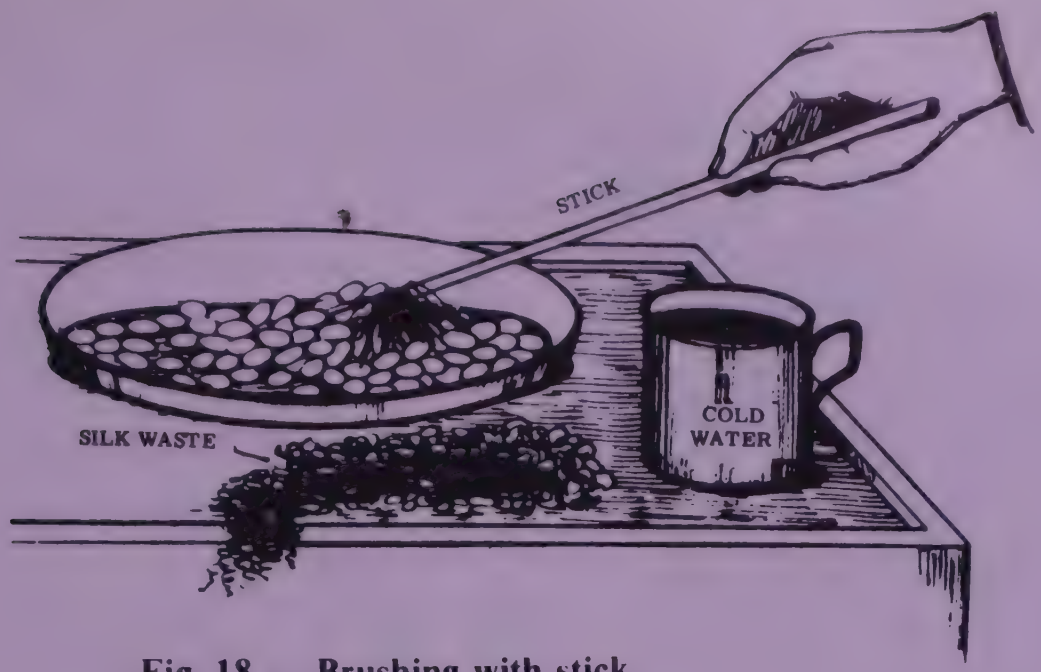


Fig. 18 — Brushing with stick

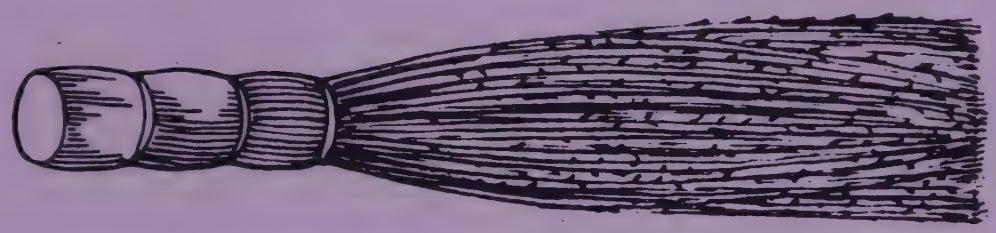


Fig. 19 — Hand-brush

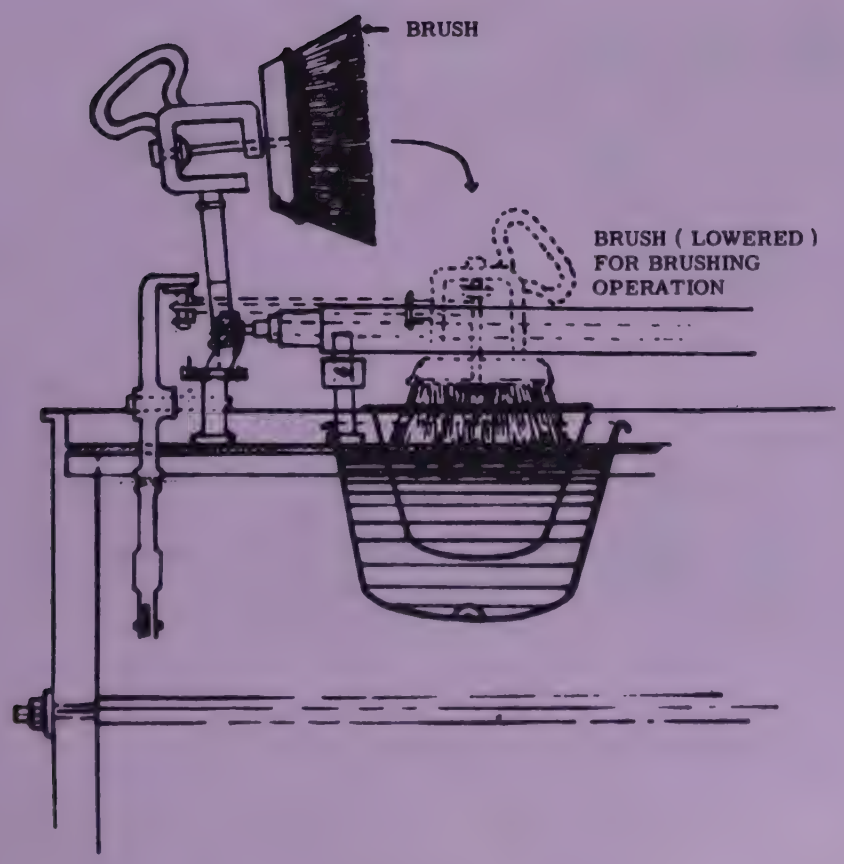


Fig. 20 — Mechanical brush

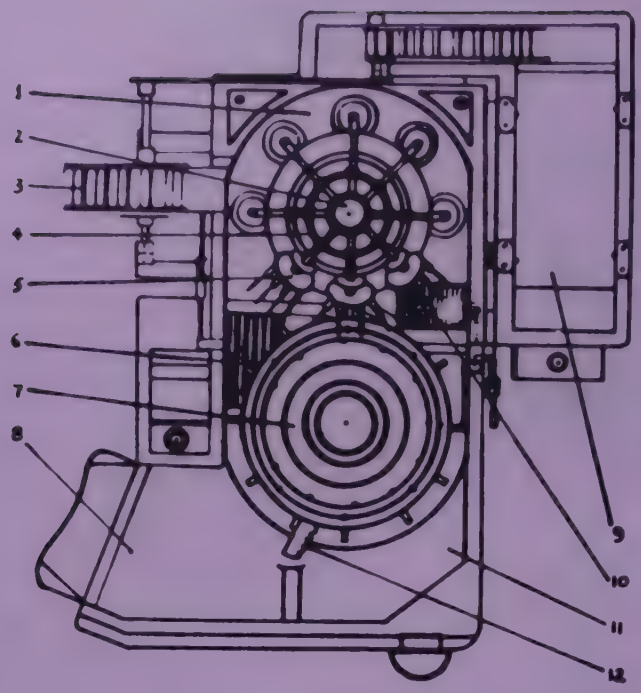


Fig. 21 — Central cocoon brushing machine

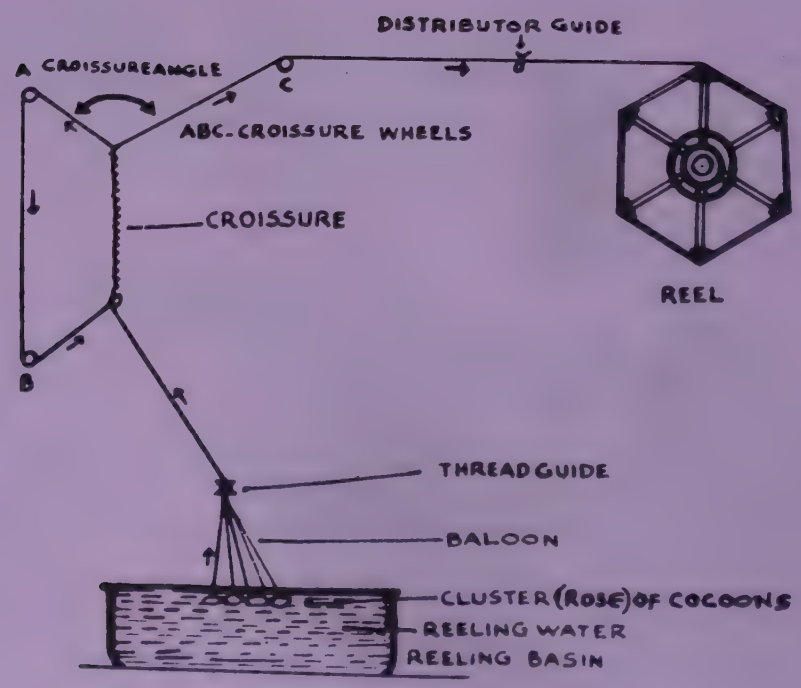


Fig. 22 — Raw silk thread formation

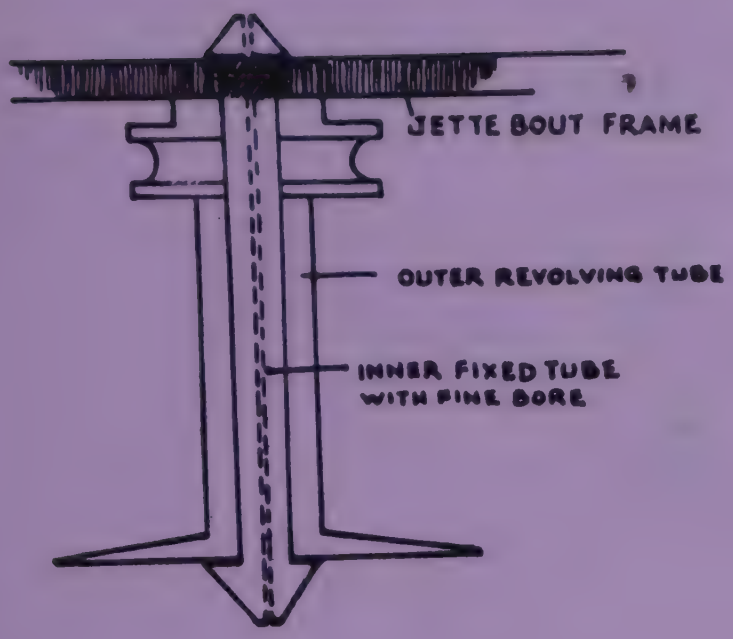
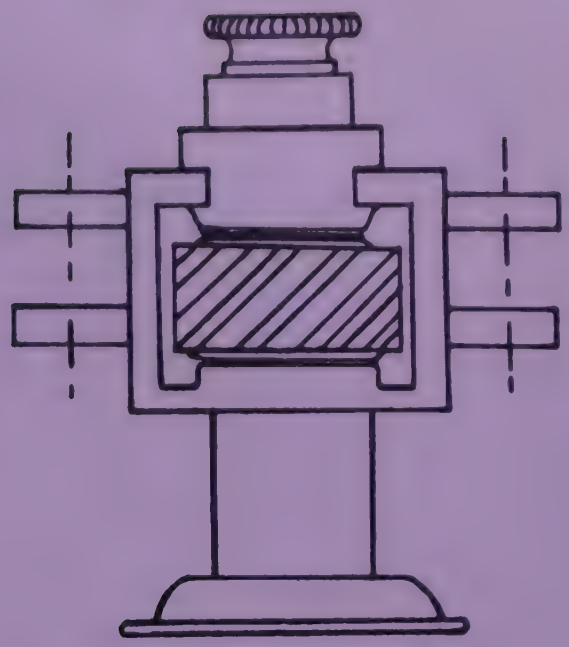


Fig. 23 — Simple jettebout for rope drive



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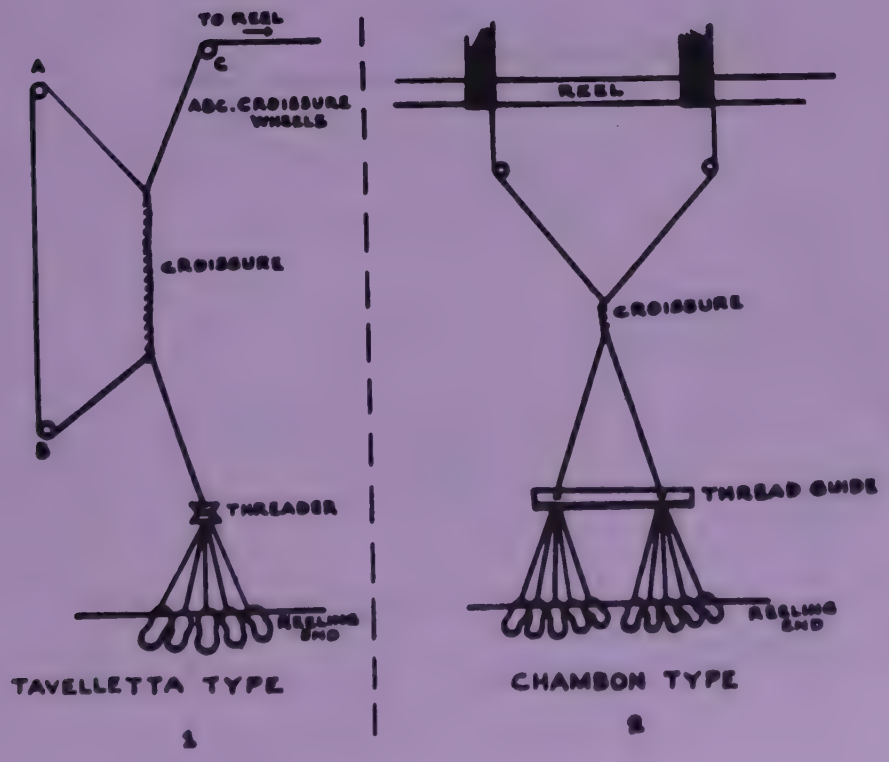

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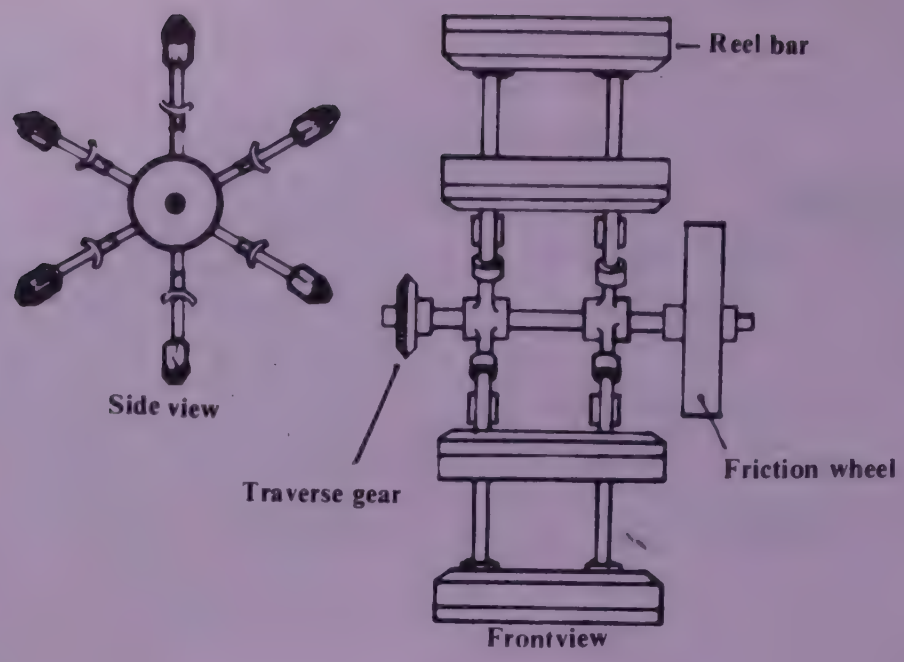

Fig. 26 — Standard reel

Fig. 27 — Primitive reel

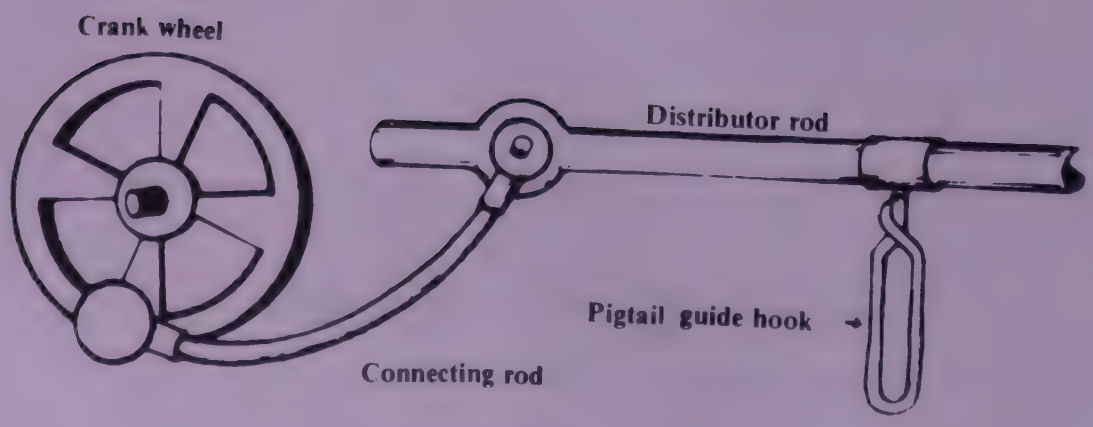

Fig. 28 — Grant reeling harmonic traverse

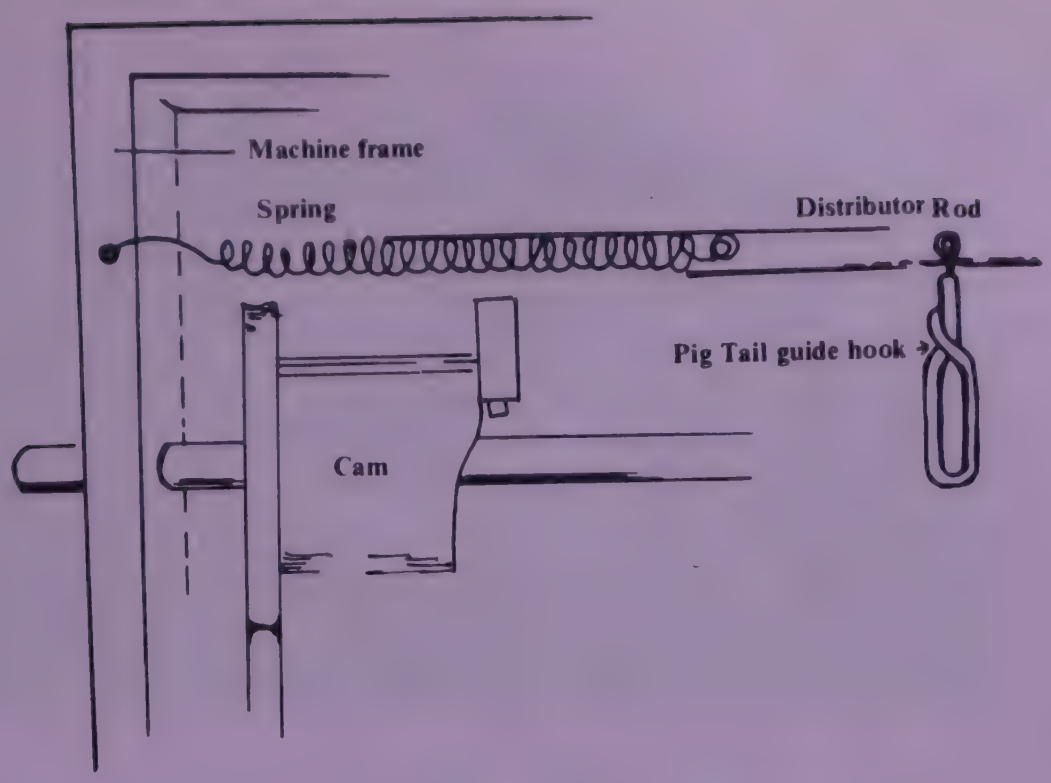

Fig. 29 — Cam type distributor

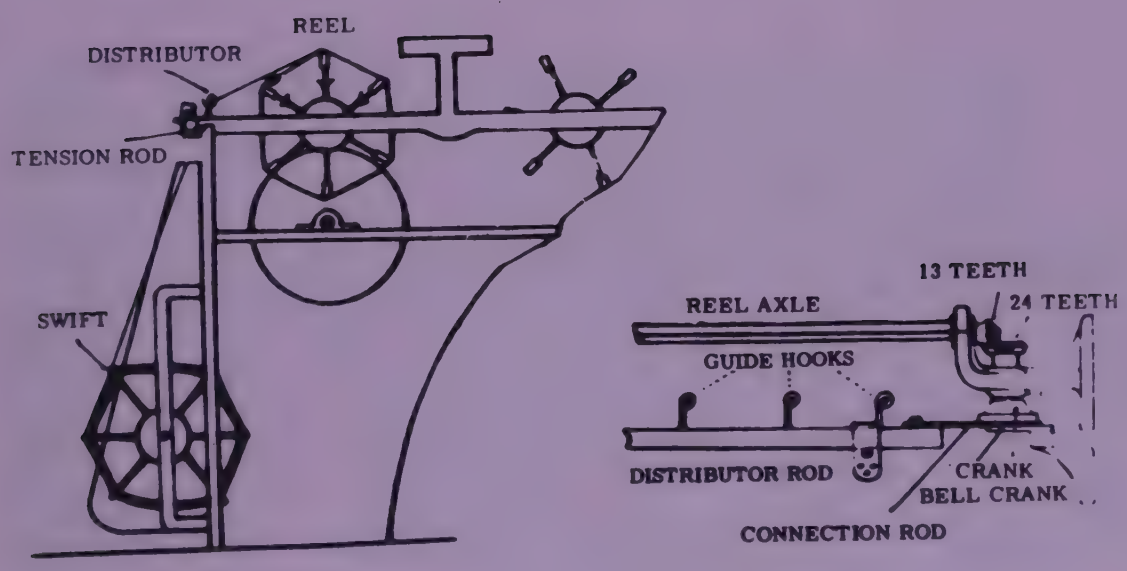

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Fig. 31 — Re-reeling from small reels

Fig. 32 — Lacing the raw silk hank

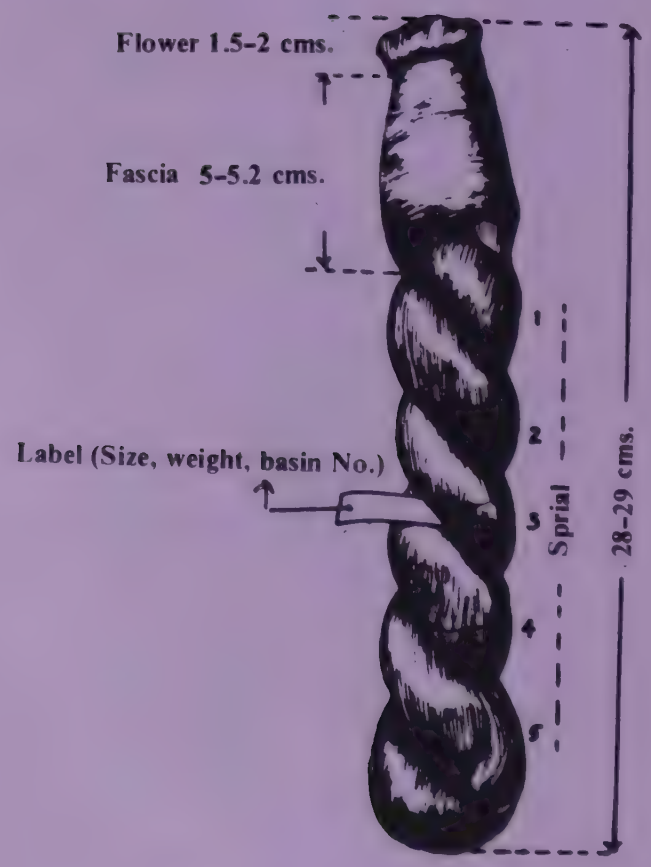


Fig. 33 — Twisted silk skein

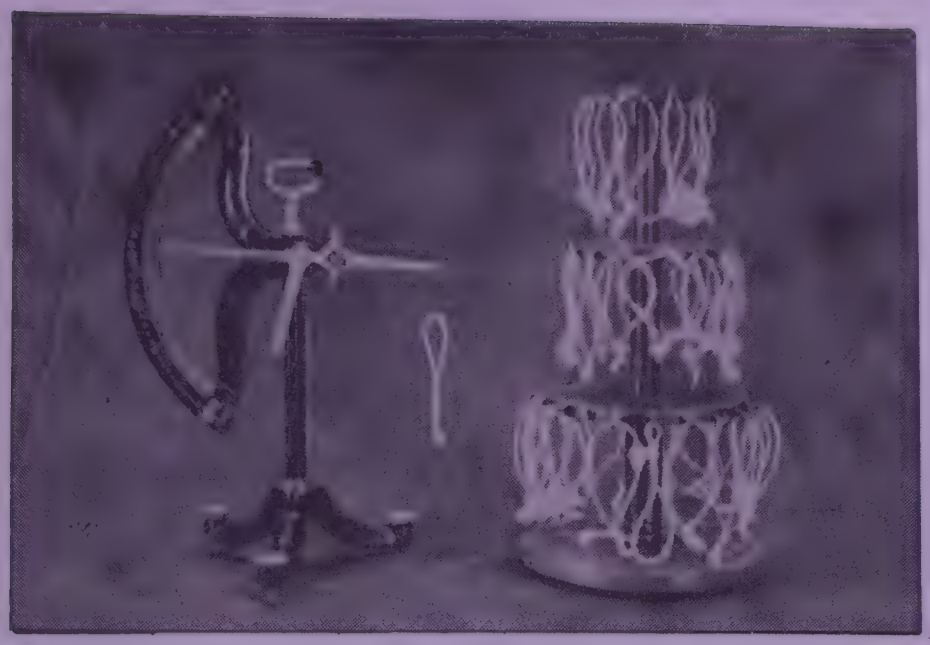


Fig. 34 — Denier scale

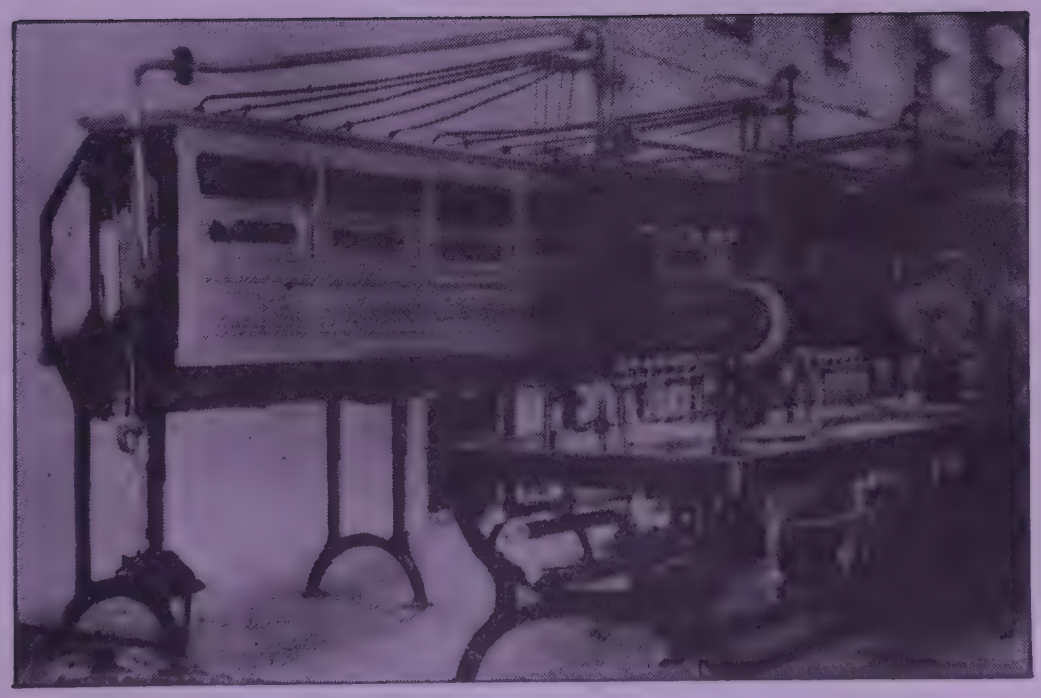


Fig. 35 — Direct reeling machine (European type)

Fig. 36 — Country Charka

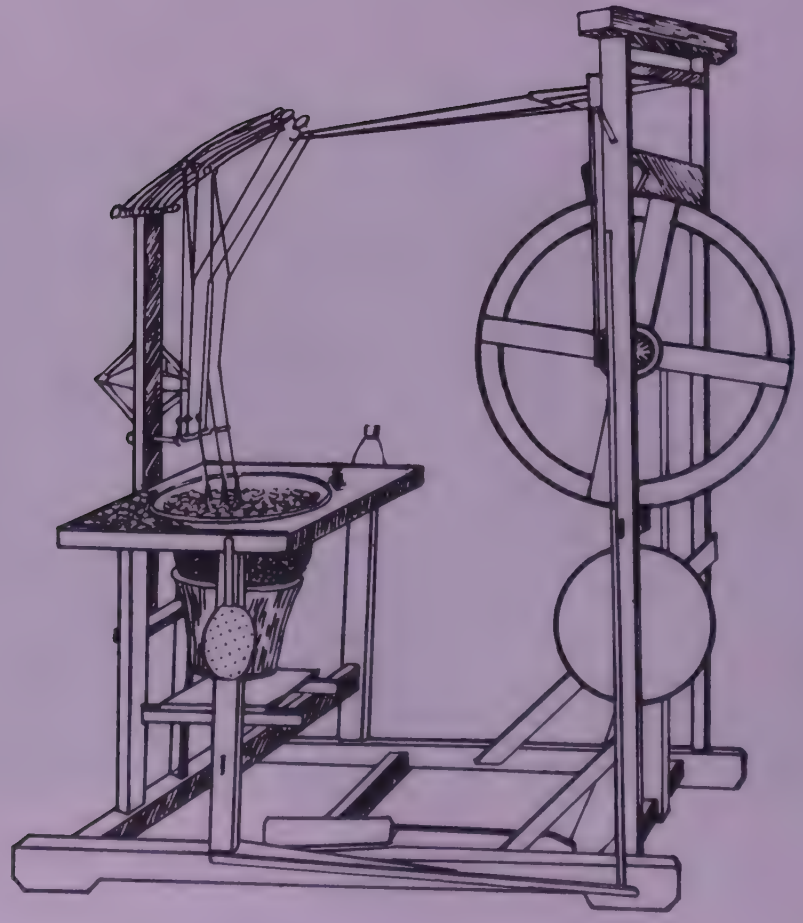
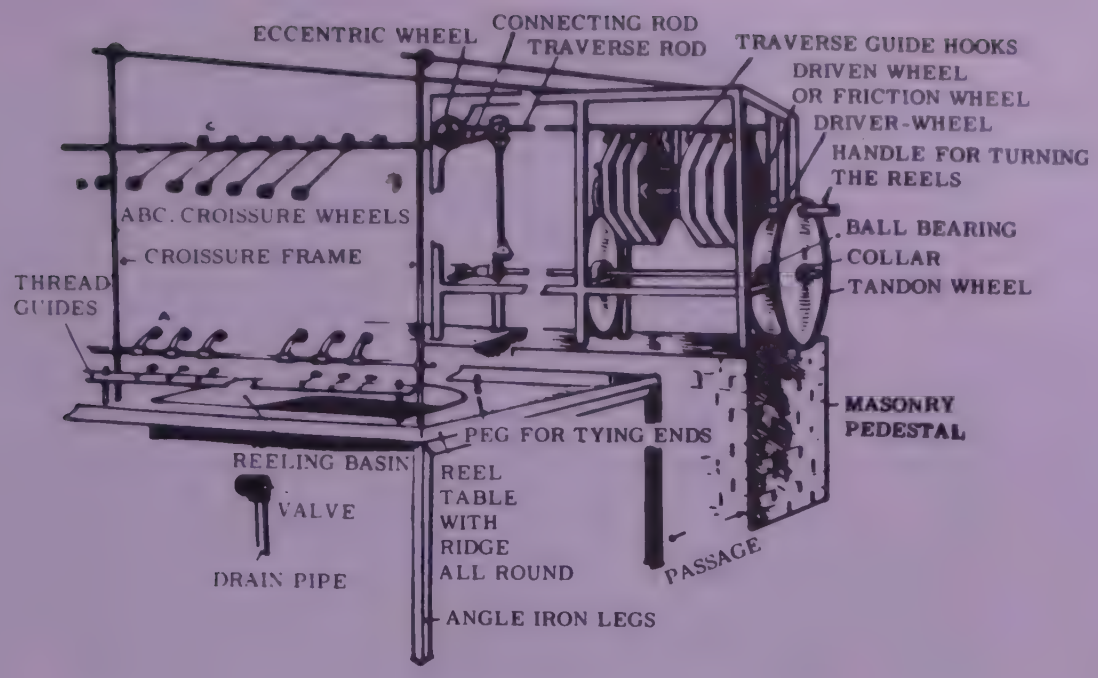


Fig. 37 — Foot-reeling machine



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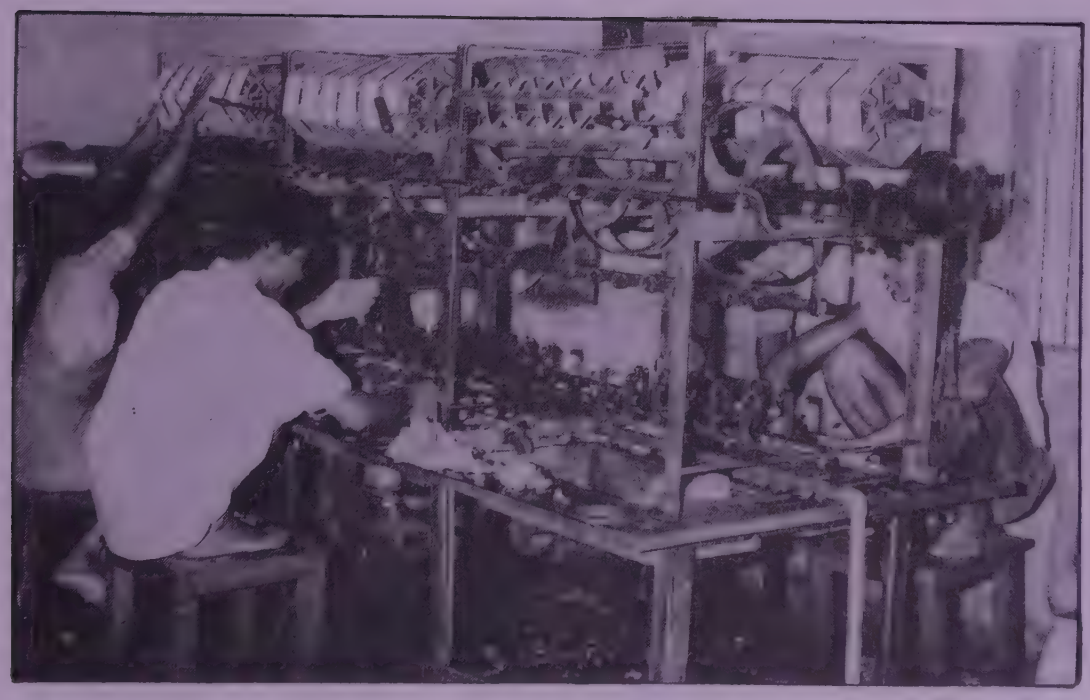

Fig. 39 — Cottage machine

Fig. 40 — Cottage machine re-reeling

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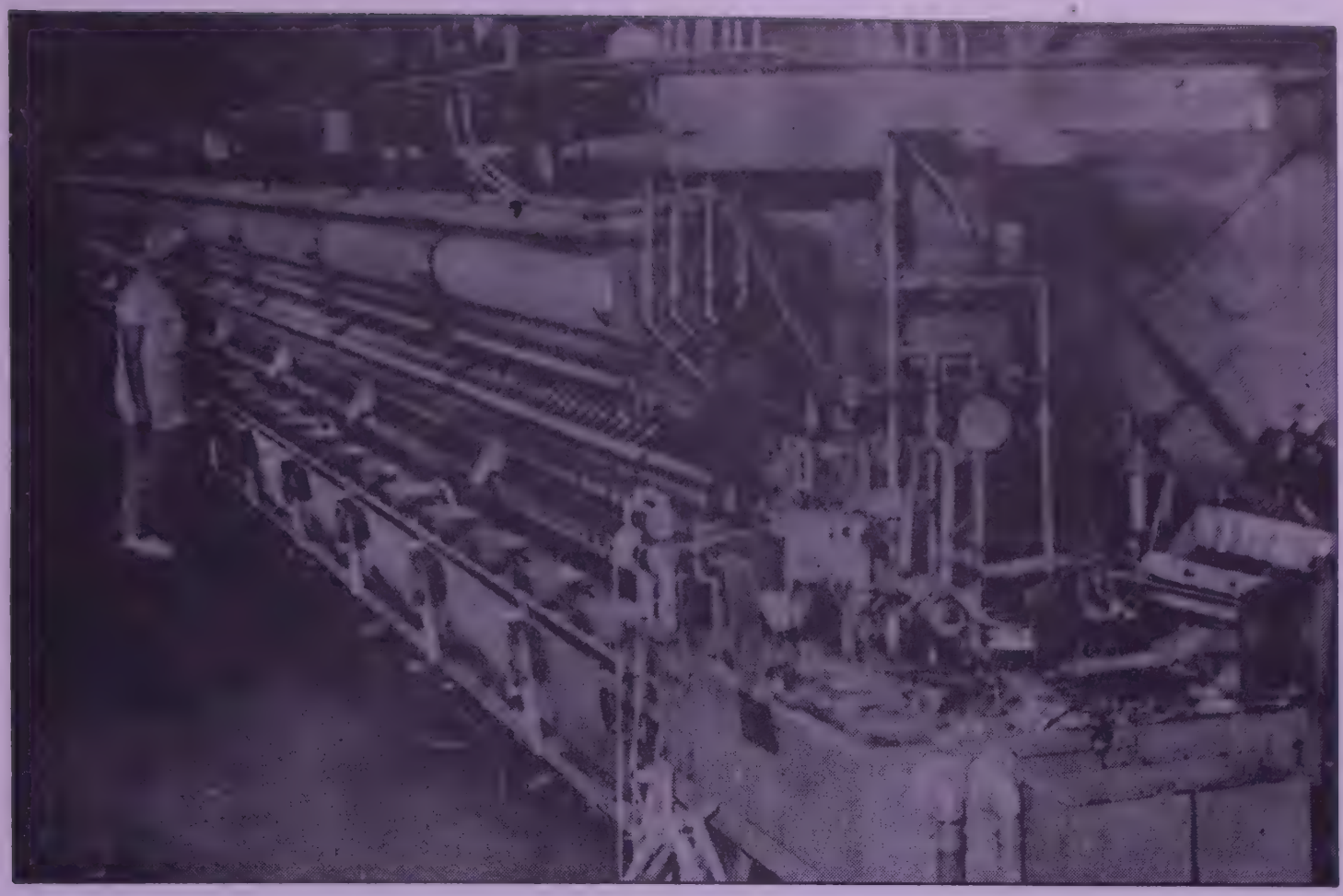

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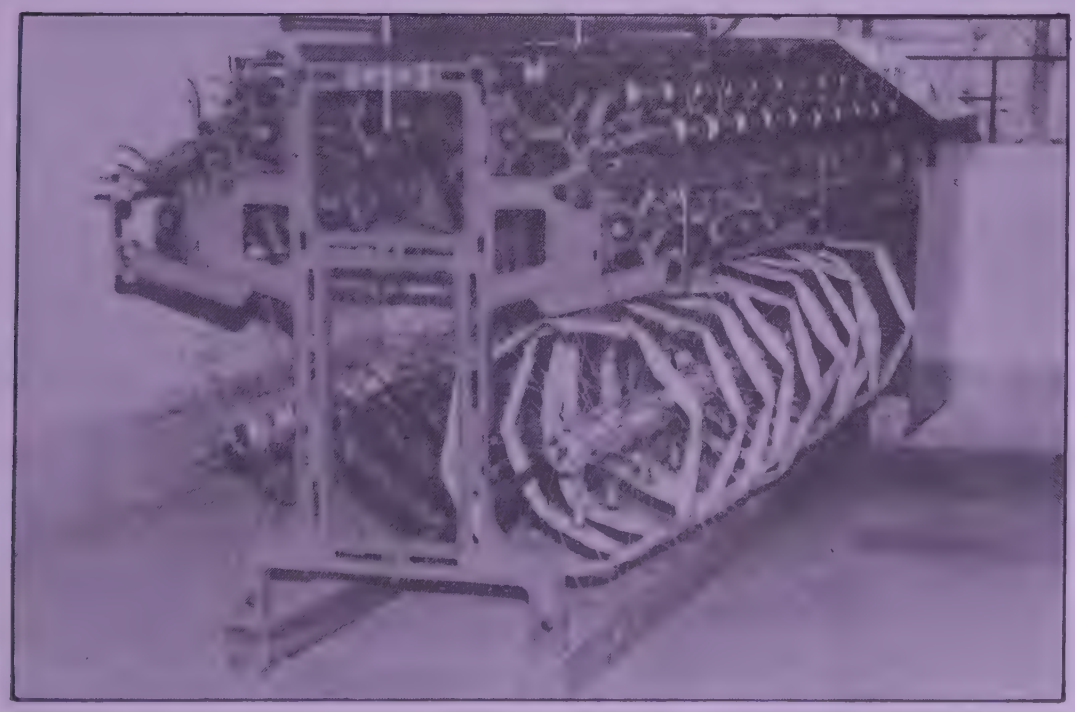

Fig. 43 — Winding frame

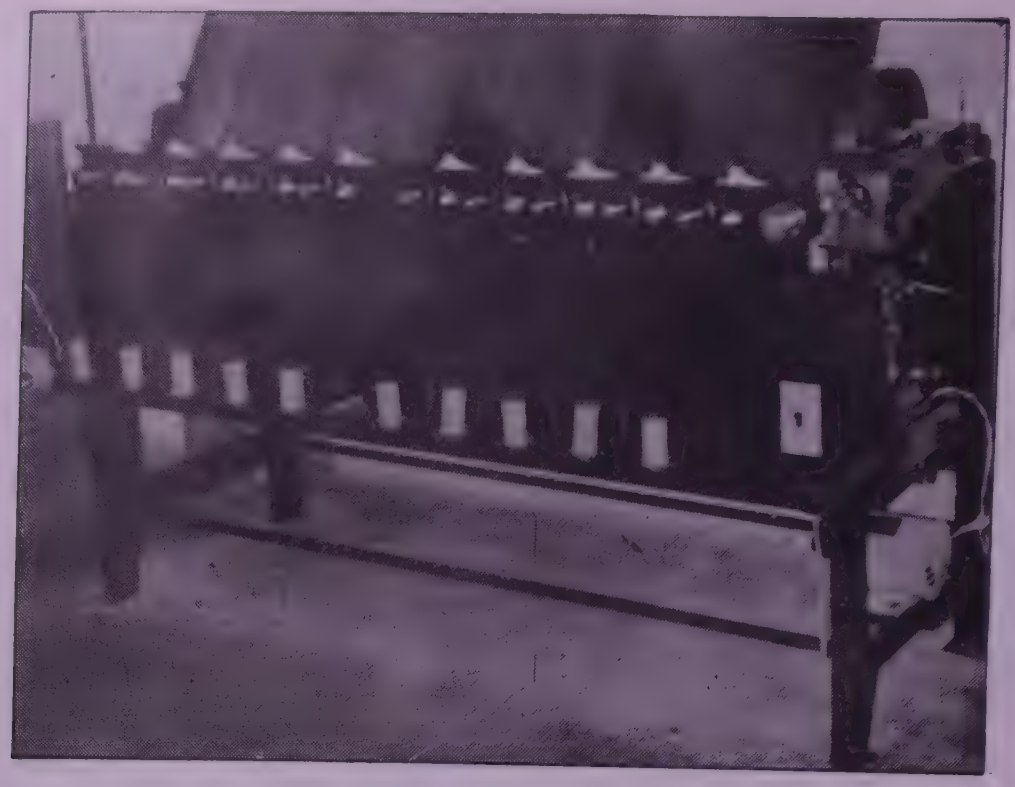

Fig. 44 — Seriplane

Fig. 46 — Serigraph

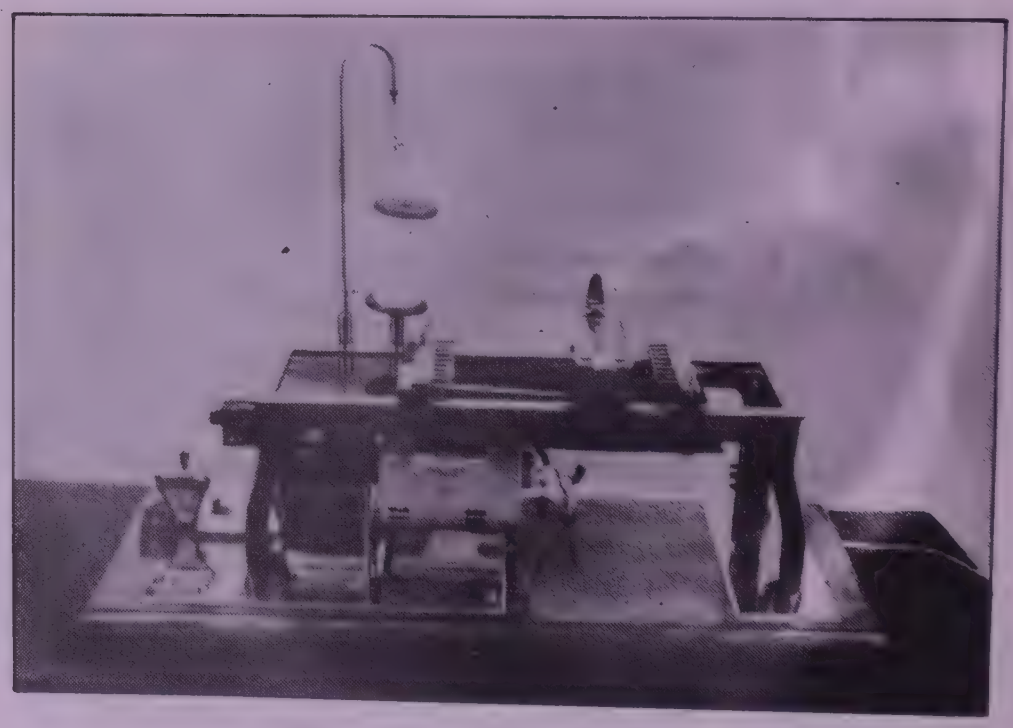

Fig. 45 — Cohesion tester

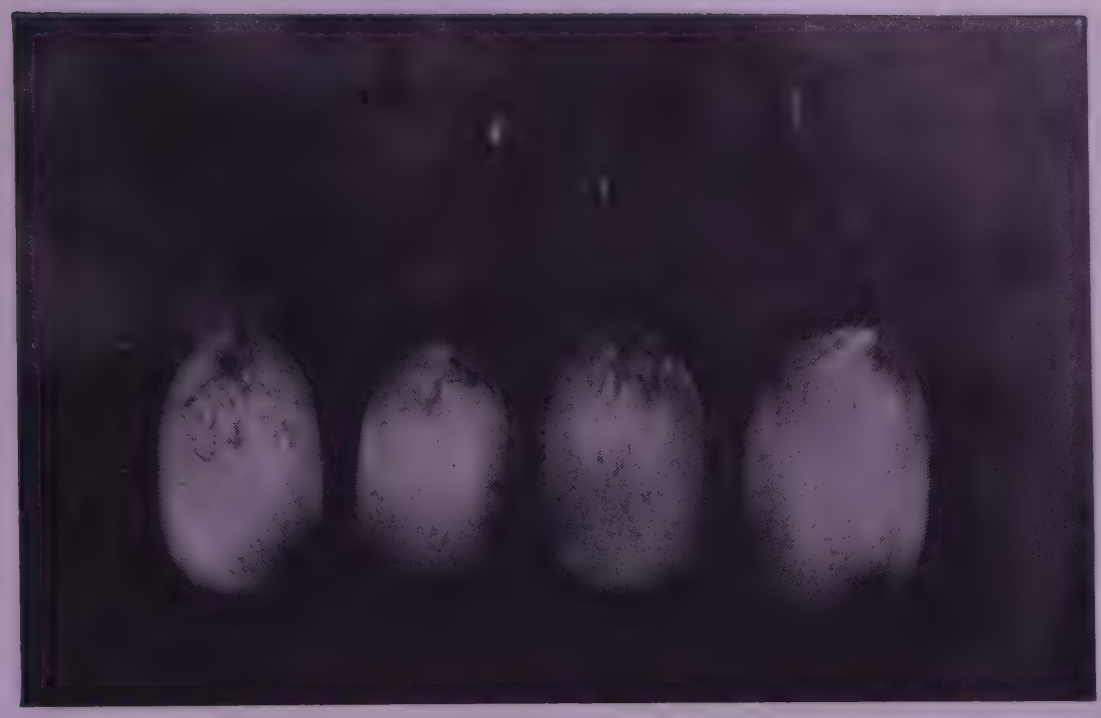

Fig. 47 — Tasar cocoons

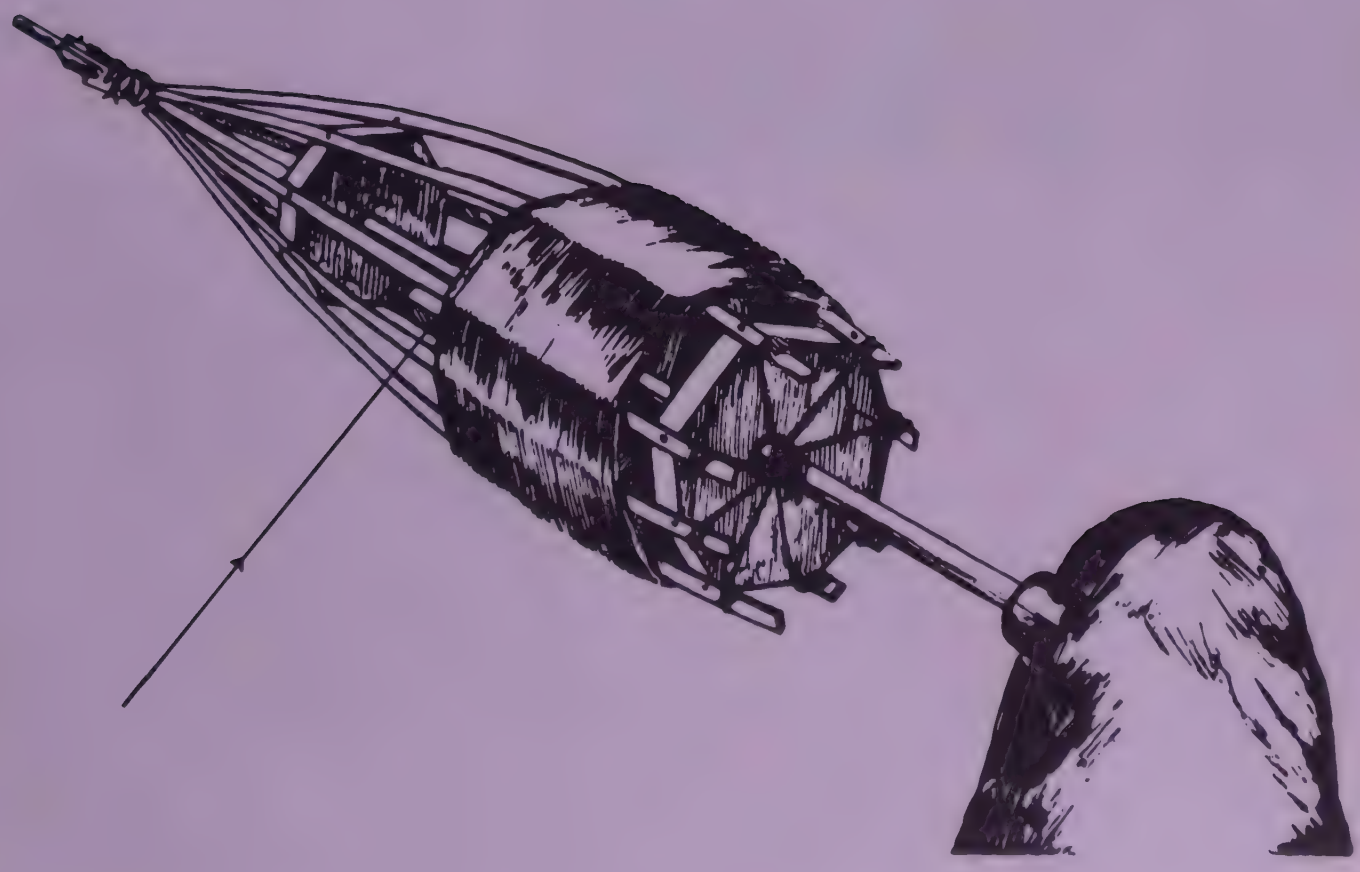

Fig. 48 — Natwa (for hand-reeling of Tasar)

Fig. 49 — Muga cocoons

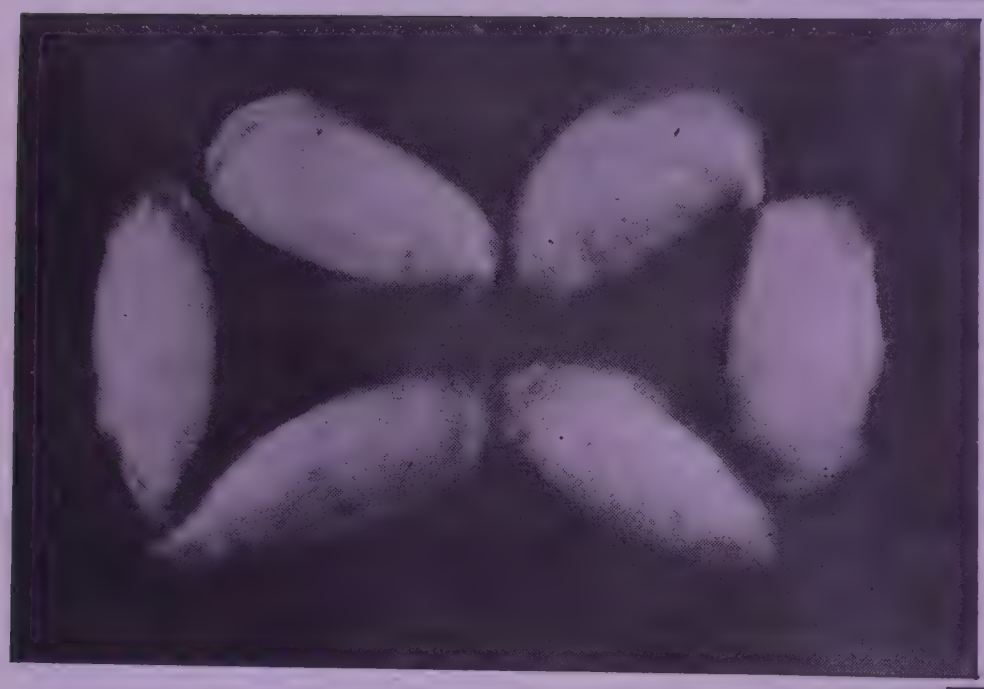

Fig. 50 — Eri cocoons

Fig. 51 — Improved Eri spinning machine

FAO AGRICULTURAL SERVICES BULLETIN

FOOD AND AGRICULTURE ORGANIZATION
OF THE UNITED NATIONS ROME

Non-Mulberry Silks

non-mulberry silks

by

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PREFACE

Agro-industry has suffered greatly from the lack of technical know-how and the non-dissemination of knowledge acquired in the different parts of the world. The same holds true for the age-old but highly potential field of non-mulberry sericulture, which has only recently caught the attention of silkmen at the international level. It was precisely for this reason that the first authentic book on tasar culture was made available to sericologists on the eve of the 1st International Seminar on Non-mulberry Silks held at the Central Tasar Research Station, Ranchi, India in October 1974.

Nevertheless, the need for a comprehensive account of the economically viable non-mulberry silk varieties was strongly felt by all concerned. The present manual on non-mulberry sericulture, which is the outcome of over a decade of dedicated research by the Indian scientists, has been written to meet that need.

This manual is not intended to be encyclopaedic in scope; rather, the authors have endeavoured to introduce the subject to sericulturists in a lucid manner, giving major emphasis to problems of practical application.

Part I of this manual discusses general aspects of the non-mulberry silk industry, and the subsequent parts deal individually with the economically important varieties: tropical tasar, temperate tasar, muga, eri and anaphe.

The authors express their heartfelt thanks to E.A. Asselbergs, Chief of the Food and Agricultural Industries Services, and M. Petruszka, Agricultural Industries Officer of FAO, Rome, for having assigned the preparation of this manual to the Central Tasar Research Station, Ranchi, India. Thanks are extended to S. Muniraju, Chairman of the Central Silk Board, Bombay, whose encouragement gave shape to this effort. The authors also gratefully acknowledge the cooperation of colleagues whose counsel has made the manual more meaningful: among them, M.M. Ahsan, S.C. Agarwal, U.P. Griyaghey, G. Das and B.D. Singh. Thanks are also due to V. Sahai, Mr. Ghanshvam and M.K. Singh. The authors express their appreciation for the services rendered by I.P. Srivastava, senior artist, and K. Swaminathan, personal assistant to the Director.

The authors will feel amply rewarded if the manual benefits those for whom it has been written. The best way to evaluate the usefulness of this publication will be the constructive comments of the users.

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Part-I

INTRODUCTION

Chapter 1

SCOPE OF NON-MULBERRY SERICULTURE

The history of silk is as long as that of civilization itself. Silk is named in legend, fable and folklore. The superiority of silk as a textile fibre has been recognized from time immemorial; the luxurious look, sleek feel and lusture of silk fabric are unquestionably inimitable. From its origin in China in about 2 200 B.C. the silk industry has had an adventurous course of evolution, becoming established from time to time in other parts of the world.

The natural silks are broadly classified as mulberry and wild or non-mulberry. Non-mulberry sericulture is universally known as forest or wild sericulture. Tropical and temperate tasar, eri, muga and anaphe are the principal non-mulberry silks; the other varieties — fagara, coan, mussel and spider — are of limited interest (Chapter 2). Nearly 95% of the global production of non-mulberry silks is tasar. The small production of other non-mulberry silks is mostly consumed in the producing countries.

1.1. Present status of the world silk industry

The annual world output of raw silk is estimated at about 48 000 metric tons of mulberry and 4 000 metric tons of tasar. Despite the best efforts of various national and international agencies, raw silk production has failed to keep up with the steadily rising demand. According to an FAO survey (40), which showed a minimum 5% annual increase in demand, it would be necessary to expand non-mulberry silk production by 20 000 metric tons over ten years. As some of the leading mulberry silk countries appear to have reached saturation point — attributable to the acute scarcity of labour and the increasing cost of production in the developed countries — there is an opportunity for the developing countries to contribute 20 000–28 000 metric tons of raw silk annually to the world's production. Precisely for this reason the untapped and highly promising field of non-mulberry silks has drawn the attention of silk users (94).

1.2. Mulberry vs. non-mulberry sericulture

All branches of sericulutre require food plants and manpower. In mulberry sericulture over 60% of the cost of production goes into raising and maintaining the food plants; besides, a heavy initial investment is necessary for rearing houses, rearing appliances and other essentials. Likewise, among the non-mulberry varieties, eri has the disadvantage of higher production costs because it is made from domesticated silkworms. Tasar, instead, has been endowed by nature with vast potential. The challenge before the sericulturists is to utilize this potential systematically so as to bring about a balanced development of the silk industry in general and of the rural economies of the developing nations in particular.

1.3. Forestry and non-mulberry sericulture

Forests not only constitute the basic means of livelihood of millions of people but also serve, for example, to regulate precipitation, conserve soil fertility and reduce erosion. Continuous deforestation since the beginning of the nineteenth century to meet the demands of industry, the wood trade, etc., is consequently a matter of grave concern (7). It is estimated that nearly 10 million hectares of the world's tropical forest is destroyed every year (14). There is danger that the short-term-benefits may override the long-term disadvantages, especially to the indigenous populations of forest regions.

Non-mulberry sericulture holds great promise for the world forestry as a supplementary activity (96). On one hand it can help arrest forest destruction, and on the other it permits gainful utilization of this vast natural wealth.

1.4 Research breakthrough

Tasar culture, the most important of the non-mulberry silk cultures, remained obscure for centuries in the hands of the tribal population. In fact, this branch of sericulture had never been accorded

any importance as in India the annual income from tasar rearing per family did not exceed Rs 250–300 (US$ 30–35). Of late, the concept of tasar culture has been radically transformed through sustained research (73, 91) into a viable and remunerative industry of immense importance, not only in India but in a number of other countries as well.

1.5 India's tasar potential

Owing to a prolific wealth of food plants, abundant manpower and ideal climatic conditions, tasar culture offers India a unique opportunity to boost her silk production and the economic status of the tribal population, the most retarded sector of her society.

Of India's total tribal population of 38 million, about 12.89 million live in the tropical tasar belt and 2.89 million in the temperate tasar belt (102). At present about 104 000 are engaged in tropical tasar culture, and only about 5 000 have so far taken up temperate tasar culture, mainly because of its recent introduction in India (Table 1).

There is a vast wealth of tasar food plants: in the tropical tasar belt an estimated 11.16 million hectares (*Terminalia, Shorea, lagerstroemia, Careya,* etc.), and in the temperate belt an estimated 1.26 million hectares (*Quercus* spp.). At present, only 5% of the area of tropical tasar food plants and hardly 0.8% of the area of temperate tasar food plants have been exploited.

If 50% of the existing food plant wealth were to be exploited systematically, the tasar industry would generate meaningful and remunerative employment for 1.25 to 1.50 million tribal familes. Furthermore, the present output of 400 metric tons of tasar raw silk with export earnings of Rs 21.63 million could be boosted to 5 000 to 6 000 metric tons with a corresponding increase in foreign exchange earnings.

1.6 Tasar culture and development

Tasar culture is a forest–based industry uniquely suited to the economy and social structure of developing countries because of its minimum investment requirement, high employment, and foreign exchange earning potential.

In India about 12.43 million hectares of unexploited tasar food plants in the tropical and temperate belts could be put to use without investment. Moreover, unlike large industries in which heavy investment is indispensable and the employment potential is limited, tasar culture requires an investment of only Rs 100 to 200/ rearer for a net return of Rs 3 000 to 4 000 in 4 to 5 months. The reeling of raw silk and the handloom weaving of fabric can keep them employed for another few months, besides practically doubling their income.

Furthermore, the various operations of tasar production can be carried out even in remote forest villages as they do not require electricity, complex machinery, specialized skills, etc. Because tasar production offers rural populations an attractive source of income, it helps arrest their migration to urban areas, thereby preserving their traditional skill and way of life. Tasar culture also simultaneously permits conservation and economic exploitation of forests.

1.7 Prerequisites for expansion of the tasar industry

Steady growth of the tasar industry is retarded by certain serious handicaps. Vertical as well as horizontal expansion will be rather difficult to achieve unless the entire infrastructure is systematically improved.

The most urgent prerequisite is organization of the seed supply (Chapter 9), which unfortunately has been thoroughly neglected in the field of tasar. It would be desirable to develop an ideal seed zone and to ensure rearers an adequate supply of disease–free and highly productive seed under the supervision of competent technical personnel.

In an Industry like tasar culture, which involves primarily backward forest or tribal propulations, extension activities assume great significance. An effective network of extension units should be organized throughout the tasar region to arrange on–the–spot demonstrations and practical training for the rearers, as well as to give technical guidance and to spread the latest applicable research findings (97).

Table 1. India's tasar production potential (In millions)

State	Total population	Tribal Total	population In tasar belts(est)	Engaged in tasar rearing	Total forest area (ha)	Est.area under tasar food plants (ha)
			TROPICAL ZONE			
Bihar	56.353	4.932	4.570	0.050	3.059	0.918
Madhya Pradesh	41.654	8.387	3.799	0.025	16.813	5.044
Orissa	21.945	5.072	2.495	0.015	6.746	2.024
West Bengal	44.312	2.533	1.091	0.010	1.183	1.355
Andhra Pradesh	43.503	1.658	0.654	0.001	6.512	1.302
Mahara-shtra	50.412	2.954	0.231	0.003	6.696	1.004
Karnataka	29.299	0.231	0.055	–	3.510	0.521
Total	287.478	25.767	12.895	0.104	44.519	11.168
			TEMPERATE ZONE			
Manipur	1.073	0.334	0.320	0.005	0.602	0.081
Nagaland	0.516	0.458	0.438	–	0.290	0.081
Mizoram	0.332	0.313	1.297	–	0.220	0.060
Arunachal Pradesh	0.476	0.369	0.361	–	5.154	0.486
Assam	14.625	1.606	0.234	–	4.422	0.106 (including Meghalaya)
Meghalaya	1.012	0.814	0.747	–	–	–
Jammu and Kashmir*	4.617	0.381*	0.303*	–	2.104	0.105
Himachal Pradesh	3.460	0.142	0.111	–	2.159	0.107
Uttar Pradesh	88.341	0.199	0.079	–	4.872	0.243
Total	114.452	4.616	2.890	0.005	19.623	1.269
Grand Total	401.930	30.383	15.785	0.109	64.142	12.437

***Scheduled caste population, as there are no tribal people in this state.**

Another serious hindrance to the launching of tasar promotion programme is the shortage of trained personnel. In view of the vast area of operation and the rapidly expanding activities of the industry, adequate training facilities for non-mulberry sericulture at various levels should be arranged. At present such training is available only at the Central Tasar Research Station, Ranchi (India), which offers five short- and long-term courses (6).

The marketing sector happens to be one of the weakest links in India's tasar industry. The middlemen penetrate the tribal areas and exploit the tasar rearers by depriving them of a fair price and by causing erratic price fluctuations. It is therefore paramount that a suitable marketing agency be established to ensure the rearers a profitable return.

A concerted programme for development of the tasar industry has been undertaken in India. Because of the heavy demand for seed, the government is seriously considering the establishment of pilot project centres for seed supply. For exploitation of at least 50% of the natural resources. It is proposed that about two thousand centres be put into operation throughout the tropical and temperate tasar belts over a period of five years.

1.8 Global potential of non-mulberry sericulture

Present information confirms a like potential for non-mulberry sericulture in a number of countries, especially in Southeast Asia, the Far East, Latin America and Africa. By applying the available knowledge and by filling in the crucial gaps with well-focussed research, a large increase in raw silk production can be realized.

Chapter 2

NON-MULBERRY SILK VARIETIES AND FAUNA

A large number of species (400–500) are used in the production of non–mulberry silks, but only about eighty have been commercially exploited in Asia and Africa, chiefly by tribal communities (133). The major varieties of non–mulberry silk are described below. All but mussel and spider silks are of insect origin. The global distribution of non–mulberry silk fauna is shown in Figure 1.

2.1 Tasar silk

Tasar silkworms are reared in the tropical and temperate zones. Four species of the genus *Antheraea* Hubner are used for commercial production: the tropical tasar silkworm: *A. mylitta* D. (India) and the temperate silkworms: *A. proylei* J. (India). *A. pernyi* G.M. (China and the U.S.S.R.) and *A. yamamai* G.M. (Japan). The silk produced by *A. assamensis* Ww. is called muga (see below), even though tasar would have been the appropriate term as it belongs to the same genus.

Antheraea comprises more species than any other genus of sericigenous insects. Thirtyfive species have been recorded (30): thirtyone in the Indo–Australian biogeographic region (166), three in the Palaeartic region (165) and one in the U.S.A. (29). Besides, there are over fifty forms/variants/aberrants/races (92) — twenty–five of *A. mylitta* alone (see Table 14).

2.2 Muga silk

The golen–yellow muga silk is secreted by a semidomesticated multivoltine species, *A. assamensis,* which is widely distributed and cultured in Assam. (The popular items made from this silk are "dhoti", "chaddar", "chapkan," "pugree" and "mekhela".

If the larvae are fed on mejankori leaves (*Litsea citrata*), *A. assamensis* produces a kind of silk known as mejankori silk, which is admired for its durability, lustre and creamy white shade. Practically the entire small output of this silk is used in Assam and neighbouring areas.

2.3 Eri silk

The white or brick–red eri silk (endi, errandi) is produced by *Philosamia ricini* Boisduval, a domesticated multivoltine silkworm. Its culture is widespread in Assam and practised on a small scale in Bihar, West Bengal, Manipur, Orissa and Tripura. The fabric made from this silk is valued by the Assamese, especially for the making of chaddars.

Philosamia Boisduval is reported (30) to comprise only one well–defined species. *P. cynthia* D., and sixteen forms/variants/aberrants/races (165, 166). Members of the genus are found in the Palaearctic and Indo–Australian biogeographic regions (Figure 1). Eri silkworms were successfully acclimatized in America and Europe in the middle of the nineteenth century, but could not take firm hold.

2.4 Anaphe silk

This silk of southern and central Africa is produced by silkworms of the genus *Anaphe: A. moloneyi* Druce, *A. panda* Boisduval, *A. reticulata* Walker, *A. ambrizia* Butler, *A. carteri* Walsingham, *A. venata* Butler and *A. infracta* Walsingham. They spin cocoons in communes, all enclosed by a thin layer of silk. The tribal people collect them from the forest and spin the fluff into a raw silk that is soft and fairly lustrous. The silk obtained from *A. infracta* is known locally as "boko", and those from *A. moleneyi* as "Tissnian–tsamia" and "koko" (5). The fabric is elastic and stronger than that of mulberry silk. Anaphe silk is used, for example, in velvet and plush.

2.5 Fagara silk

Fagara silk is obtained from the giant silk moth *Attacus atlas* L. and a few other related species or races inhabiting the Indo–Australian biogeographic region, China and the Sudan. They spin light–brown cocoons nearly 6 cm long with peduncles of varying lengths (2–10 cm).

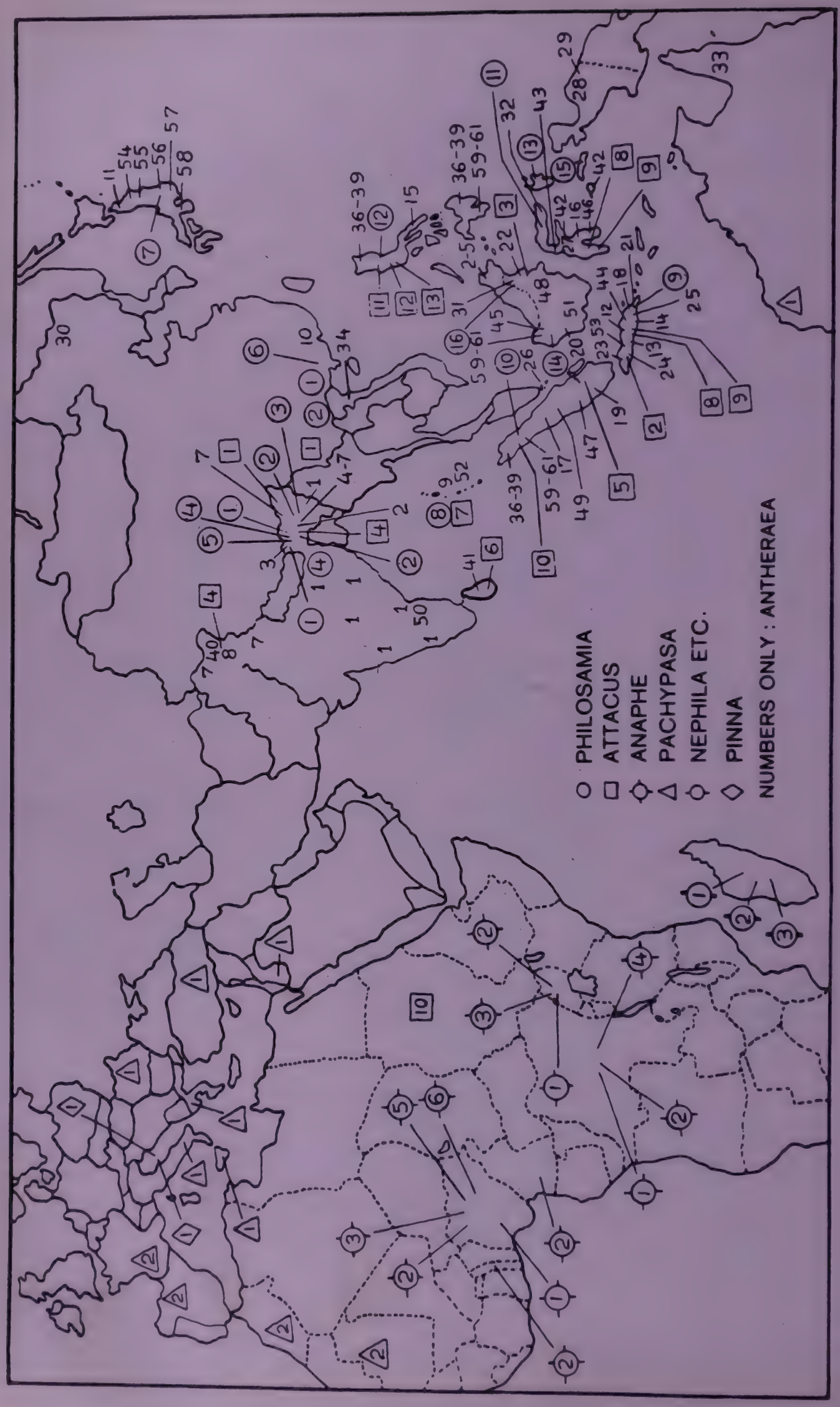


FIGURE 1. Global distribution of non-mulberry silk fauna

Figure 1. **Global distribution of non-mulberry silk fauna***

Key to Figure 1

Antheraea (tasar)

1. *A. mylitta* D.
2. *A. assamensis* Ww.
3. *A. knyvetti* Hmps.
4. *A. compta* R. & J.
5. *A. frithii* Mr.
6. *A. helferi* Mr.
7. *A. roylei* Mr.
8. *A. sivalica* Mr.
9. *A. andamana* Mr.
10. *A. pernyi* G.M.
11. *A. yamamai* G.M.
12. *A. pasteuri* Bouv.
13. *A. raffrayi* Bouv.
14. *A. jana* Stoll
15. *A. semperi* Fldr.
16. *A. cordifolia* Weym.
17. *A. pratti* Bouv.
18. *A. imperator* Wts.
19. *A. brunnea* Eecke
20. *A. billitonensis* Mr.
21. *A. larissa* Ww.
22. *A. ridleyi* Mr.
23. *A. prelarissa* Bouv.
24. *A. surakarta* Mr.
25. *A. mylittoides* Bouv.
26. *A. delegata* Swh.
27. *A. fickei* Weym
28. *A. pristina* Wkr.
29. *A. sciron* Ww.
30. *A. harti* Mr.
31. *A. gephyra* Niep.
32. *A. rumphi* Fldr.
33. *A. eucalypti* Sott.
34. *A. larissoides* Bouv.
35. *A. polyphemus* Cram.
36. *fasciata* Mr.
37. *versicolor* Mr.
38. *pulchra* Mr.
39. *ochripicta* Mr.
40. *fraterna* Mr.
41. *cingalesa* Mr.
42. *celebensis* W. & S.
43. *buruensis* Bouv.
44. *subcaeca* Aurvil
45. *fusca* Roth.
46. *minahassae* Niep
47. *sumatrana* Niep
48. *borneensis* Mr.
49. *korintjina* Bouv.
50. *perrotteti* Guer
51. *yongei* Wts.
52. *insularis* Wts.
53. *javanensis* Bouv.
54. *hazina* Butt.
55. *calida* Butl.
56. *morosa* Butl.
57. *fentoni* Butl.
58. *sergustus* Ww.
59. *nebulosa* Hutt.
60. *olivescens* Mr.
61. *platessa* Roth.

Philosamia (eri)

1. *P. cynthia* D.
2. *ricini* Boisd.
3. *lunuloides* Reb.
4. *obscura* Btl.
5. *canningii* Hutt.
6. *walkeri* Fldr.
7. *pryeri* Butl.
8. *fluva* Jord.
9. *insularis* Voll.
10. *vaneeckei* Wts.
11. *vanderberghi* Wts.
12. *luzonica* Wts.
13. *tetrica* Rbl.
14. *borneensis* Rbl.
15. *ceramensis* Bouv.
16. *mindanaensis* Rbl.
17. *advena* Pack.

Attacus (fagara)

1. *A. atlas* L.
2. *A. standingeri* Roth.
3. *A. crameri* Fldr.
4. *A. edwardsi* White
5. *A. dohertyi* Roth.
6. *taprobanis* Mr.
7. *macmulleri* Wts.
8. *simalurana* Wts.
9. *erebus* Fruhst.
10. *gladiator* Fruhst.
11. *lorquinii* Fldr.
12. *caesar* M. & W.
13. *imperator* Ky.

Anaphe

1. *A. infracta* Wals.
2. *A. venata* Butl.
3. *A. moloney* Druce
4. *A. panda* Boisd.
5. *A. reticulata* Walk.
6. *A. carteri* Wals.

Nephila, etc. (spider)

1. *N. madaguscarensis*
2. *Miranda* aurentia
3. *Epeira* spp.

Pachypasa (coan)

1. *P. otus* D.
2. *P. lineosa* Vill.

Pinna (mussel)

1. *P. squamosa*

**Antheraea polyphemus* and (*Philosamia*) *advena* are endemic in the U.S.A.

2.6 Coan silk

The larvae of *Pachypasa otus* D., from the Mediterranean biogeographic region (southern Italy, Greece, Romania, Turkey, etc.), feed primarily on trees such as pine, ash, cypress, juniper and oak. They spin white cocoons measuring about 8.9 x 7.6 cm. In ancient times this silk was used to make the crimson-dyed apparel worn by the dignitaries of Rome; however, commercial production came to an end long ago because of the limited output and the emergence of superior varieties of silk.

2.7 Mussel silk

Whereas the non-mulberry silks previously described are of insect origin, mussel silk is obtained from a bivalve, *Pinna squamosa,* found in the shallow waters along the Italian and Dalmatian shores of the Adriatic. The strong brown filament, or byssus, is secreted by the mussel to anchor it to a rock or other surface. The byssus is combed and then spun into a silk popularly known as "fish wool". Its production is largely confined to Taranto, Italy.

2.8 Spider silk

Spider silk — another non-insect variety — is soft and fine, but also strong and elastic. The commercial production of this silk comes from certain Madagascan species, including *Nephila madagascarensis, Miranda aurentia* and *Epeira.* As the spinning tubes (spinne-rules) are in the fourth and fifth abdominal segments, about a dozen individuals are confined by their abdominal part to a frame from which the accumulated fibre is reeled out four or five times a month.

Because of the high cost of production, spider silk is not used in the textile industry; however, durability and resistance to extremes of temperature and humidity make it indispensable for cross hairs in optical instruments.

Chapter 3

PRODUCTION AND MARKETING

Non-mulberry silks are commercially produced mainly in China and India. The annual global output of raw silk is estimated at nearly 4000 metric tons, of which about 80% is produced in China. Because of the unavailability of authoritative information from China, the following discussion is restricted to non-mulberry silk production and marketing in India.

Climate and vegetation provide India with an abundance of non-mulberry sericigenous fauna (65). Only India produces on a significant scale all the important varieties of non-mulberry silks: tropical and temperate tasar, eri and muga. (Figure 2).

3.1 Production and trends

The current level of tropical tasar production is about 260 000 kahans (1 kahan = 1 280 cocoons) of reeling cocoons, 400 metric tons of raw silk and 150 metric tons of silk waste — of which Bihar accounts for more than half (Table 2). The raw silk output of Madhya Pradesh is not proportionate to that state's cocoon output, as cocoons are brought from other states to meet the shortage in the tasar weaving sector. Manipur, where temperate tasar has been introduced, currently produces about 1 400 kahans of cocoons.

Assam not only monopolizes muga silk production but is also the largest producer of eri cocoons. Almost the entire cocoon production of the northeastern states (Tripura, Meghalaya, Bihar, etc.) is sent to Assam, which accounts for over 95% of India's eri spun silk and silk waste production.

In the period 1966–75, tropical tasar production expanded almost steadily (Table 3).

3.2 Marketing system

Cocoons are sold at the local weekly market ("haat"). Eri cocoons are marketed by weight, and tasar and muga cocoons by number. Tropical tasar cocoons are sold in local numerical lots: ganda (4 cocoons), pan (80), kahan (1 280 in Bihar, 1 600 in Orissa, 1 000 in Madhya Pradesh and khandi (in Maharashtra 4 000). Transactions for raw silk, waste and handspun yarn of all varieties of non-mulberry silk are by weight.

The prices of silk products increased by 100 to 200% in the period 2966–75. Cocoons rose from Rs 65 to 168/kahan of tasar, from Rs 10 to 31/kg of eri and from Rs 24 to 65/thousand for muga. For tasar the prices of raw silk, waste and handspun yarn per kg increased by 1975 to Rs 250 (estimated), 36 and 89 from their 1966 levels of Rs 86, 19 and 30, respectively. Comparable price increases were registered in the corresponding period for handspun eri yarn (from Rs 44 to 70), raw muga silk (from Rs154 to 291) and muga waste (from Rs 8 to 18).

Rearers, reelers and weavers are severely handicapped by the lack of a proper marketing organization. This retards an orderlygrowth of the non-mulberry silk industry.

Agencies of the various state governments have organized a network of cooperatives to ensure a minimum remunerative price to tasar rearers. The Government of India is actively considering the setting up of an All India Tasar Corporation for more efficient marketing. Eri cocoons are sold at reasonable prices to the government-owned Assam Spun Silk Mill, by far the largest buyer. Muga is marketed through cooperatives and certified khadi institutions which safeguard the interests of the cultivators.

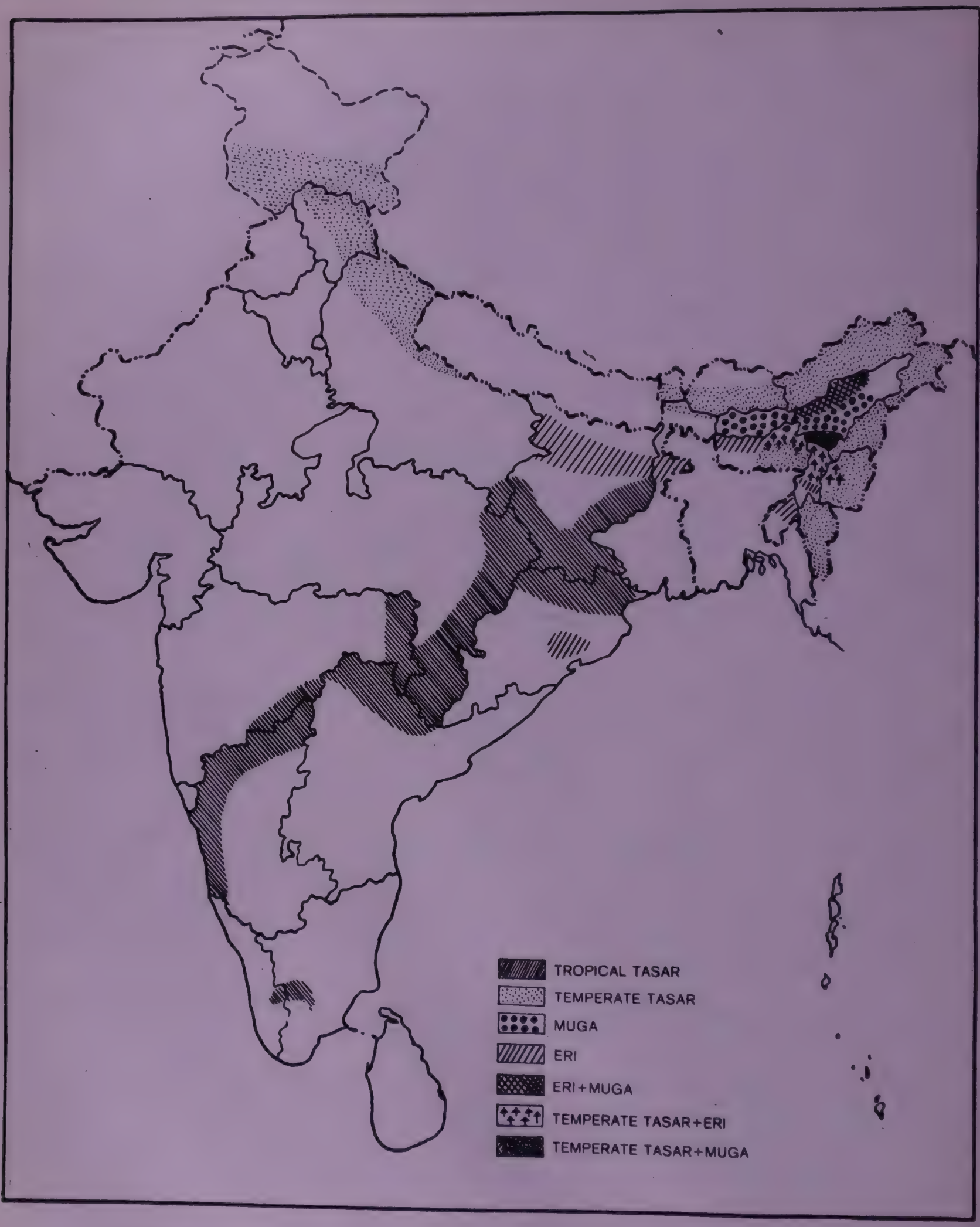


FIGURE 2. Territorial spread of non-mulberry sericulture in India

State	Cocoons			Raw and spun silk			Waste		
	Tasar	Eri	Muga	Tasar	Eri	Muga	Tasar	Eri	Muga
Bihar	52.3	4.7	–	59.5	3.2	–	63.8	3.2	–
Madhya Pradesh	18.6	–	–	29.7	–	–	23.6	–	–
Orissa	8.4	–	–	4.8	–	–	6.5	–	–
West Bengal	14.5	–	–	5.4	–	–	5.2	–	–
Assam	–	71.7	100.0	–	95.5	100.0	–	96.4	100.0
Meghalaya	–	9.4	–	–	–	–	–	–	
Tripura	–	12.9	–	–	–	–	–	–	–
Others	6.2	1.3	–	0.6	1.3	–	0.9	0.4	–

Table 3. Non-mulberry silk production in India, 1966–75

(In thousands)

Year	Cocoons			Raw and spun silk				Waste			
	Tasar (Kahans)	Eri (kg)	Muga (no.)	Tasar (kg)	Eri (kg)	Muga (kg)	Total (kg)	Tasar (kg)	Eri (kg)	Muga (kg)	Total
1966	228	322	3 000	268	208	68	544	173	66	23	262
1967	248	333	3 200	281	211	69	561	159	67	22	243
1968	217	363	3 700	292	211	70	573	133	72	25	230
1969	139	343	3 600	252	216	72	540	135	76	30	241
1970	225	274	2 380	353	164	69	586	167	33	28	248
1971	177	275	3 900	335	170	72	577	165	55	25	245
1972	255	223	3 300	281	146	65	492	134	49	21	204
1973	280	283	3 600	386	149	73	608	178	86	24	288
1974	296	170	1 100	392	91	41	524	152	28	10	190
1975 (est)	264	182	400	395	121	27	543	168	43	13	224

3.3 India's exports of tasar silk

Whereas the entire eri and muga production is still absorbed domestically, tasar has become a perennial earner of foreign exchange. India exports mainly finished tasar products, including saris, scarves, dress material, ready-made clothing and ties.

After an abrupt decline in 1970 and 1971, India's foreign exchange earnings from tasar began to rise again, reacing a record high in 1975, despite the continuing world recession and related trade difficulties (Table 4).

Indian tasar is sold in over twenty countries (Table 5). Since 1968 the Federal Republic of Germany has been the major outlet; in 1975 it accounted for over 60% of the total export earnings. In the U.S.A., once the largest importer, demand fell sharply in the early 1970s; however, with a reversal in trend the export earnings from the U.S.A. rose by 1975 to second place. The sharp decrease in exports to Japan in 1975 was probably a consequence of the critical state of her domestic silk market.

India also exports small quantities of tasar waste, mainly to the Republic of Korea, Italy and Japan.

Table 4. India's tasar exports and foreign exchange earnings, 1966–75

(In millions)

Year	Quantity (m^2)	Value (Rs)	Year	Quantity (m^2)	Value (Rs)
1966	0.324	4.615	1971	0.645	11.508
1967	0.371	5.418	1972	0.676	13.586
1968	0.913	13.195	1973	0.891	20.086
1969	1,276	19.688	1974	0.817	20.560
1970	0.782	13.690	1975	0.804	21.631

Table 5. India's export earnings from tasar silk by country, 1966–75

(Thousand rupees)

Country	1966	1968	1970	1972	1973	1974	1975
Germany, F.R.	554	3 024	5 184	6 949	10 840	10 708	13 053
Sweden	80	2 947	1 007	381	950	1 089	523
Japan	247	2 600	1 789	1 532	1 290	4 416	143
U.S.A.	2 677	1 597	574	1 210	1 889	2 331	2 626
Switzerland	66	331	390	524	641	911	438
Denmark	22	481	448	139	61	225	36
Australia	71	412	475	249	136	149	68
Italy	41	43	1 026	650	837	577	462
France	14	235	1 056	1 112	741	632	1 060
Hong Kong	483	509	380	156	144	247	226
U.K.	84	255	267	280	647	742	866
Finland	16	57	142	101	325	192	144
Canada	192	378	110	209	302	584	418
Austria	6	38	174	441	357	739	635
Malaysia and Singapore	3	66	102	244	221	281	190
Netherlands	8	6	114	36	51	53	130
Belgium	7	41	46	35	33	54	90
Yugoslavia	–	98	9	–	58	60	142
Others	44	147	339	338	572	604	381
Total	4 615	13 195	13 572	13 586	20 085	20 560	21 631

Part-II

TROPICAL TASAR

The word tasar apparently derives from the Sanskrit word *trasara* (shuttle). Tasar silk is mentioned in literature dating back to 1590 B.C. India's illustrious tradition of tasar production is often regarded as a symbol of her tribal cultures.

The master creators of the world-famous Indian tasar belong to aboriginal (*adivasi*) forest peoples (e.g., Ho, Santal, Kol, Baiga, Budha and Telege) which have been rearing tropical tasar for centuries. During cultivation these peoples perform various rituals and keep the cocoons in their thatched huts for protection from natural enemies.

The dense, humid tropical forest sprawling over the central and southern plateau is the habitat of tropical tasar. The major cocoon-producing districts are Singhbhum and Santhal Pargana in Bihar; Raigarh and Jagdalpur in Madhya Pradesh; Mayurbhanj and Keonjhar in Orissa; Purulia and Bankura in West Bengal; Bhandara in Maharashtra; Adilabad and Warangal in Andhra Pradesh; Belgaum in Karnataka.

Chapter 4
MORPHOLOGY

The genus *Antheraea* Hubner belongs to the superfamily Bombycidae and the family Saturniidae. This family is characterized by prominent bipectinate antennae in both sexes, minute labial palpi, short maxillae and a lack of frenulae. It includes a number of tropical and a few temperate sericigenous insects with a transparent eyespot at the centre of each wing. the larvae are stout and smooth and have rudimentar scoli. *A. mylitta* Drury is the most important member of this genus.

4.1 Egg

The egg is oval, dorsoventrally flattened and bilaterally symmetrical along the anteroposterior axis. About 3 mm in length and 2.5 mm in diameter, it weighs approximately 10 mg (72). At oviposition it is dark brown owing to the gummy coating of meconium; on washing, however, it becomes white, light yellow or creamy. Two brownish parallel lines along the equatorial plane of the egg divide the surface into three zones: disk, streak and edge (Figure 3) (see Chapter 13).

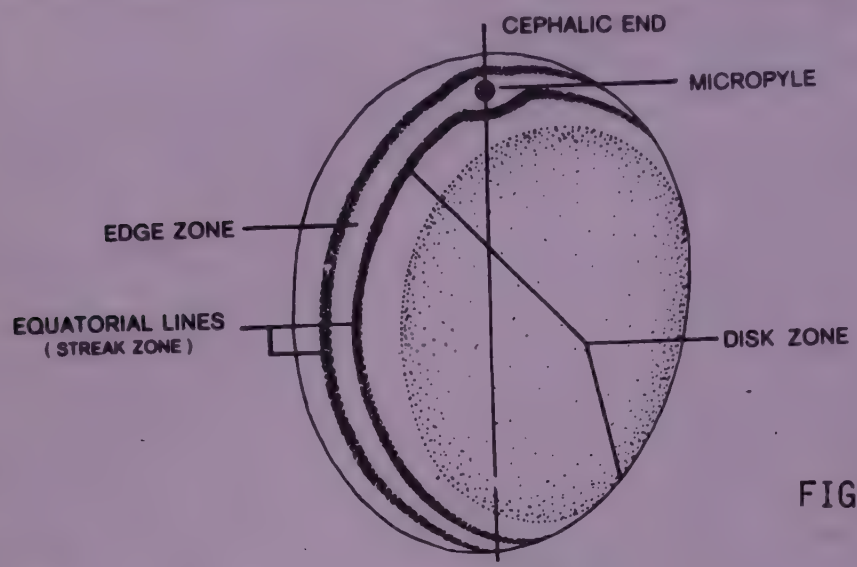


FIGURE 3. Diagram of the *A. mylitta* egg

4.2 Larva

The larva is typically eruciform and has a hypognathous head (Figure 4) with biting and chewing mouthparts. On hatching it is dull brownish yellow with black head, measures about 7 x 1 mm, and weighs about 8 mg. The body normally turns green and the head brown after about 48 hours (92), but also yellow, blue and almond-coloured larvae are met with occasionally. The body colouration is retained throughout the larval period. The size and weight at maturity are about 13 x 2.1 cm and 50 g.

The prothoracic hood of the first-instar larvae dorsally bears an oval black spot, which early in the second instar becomes M-shaped and then, later on, V-shaped with two dots (136). These marks are absent in the third instar, but reappear in the fourth and fifth instars as two semilunar red markings corresponding to the epicranial plates (Figure 5).

The anal flap bears a triangular black mark early in the first instar, which becomes V-shaped and brownish from the second instar onward. The triangular mark on each of the claspers is black in the first two instars and brown in the succeeding instars.

Early in the first instar the Larvae have a black mid-dorsal line extending from the first to the seventh abdominal segment and a dum-bell-shaped black mark on the eighth segment. Laterally, the first seven abdominal segments have a pair of black vertical lines, and on the eighth abdominal segment there is a single oblique line. The vertical lines are replaced by V-shaped marks late in the first instar. Each of the abdominal feet bears a horizontal black mark. All these markings disappear in the later stages of development. First to fifth-instar larvae have a red mid-ventral line extending the length of the abdomen. Third-instar larvae have a yellow lateral line extending from the second to the tenth abdominal segment. This line is bordered by a brown upper line in fourth-and fifth-instar larvae. The sexual markings appear late in the fifth instar as milky white spots on the ventral surface of the eighth and ninth abdominal segments (Figure 6)

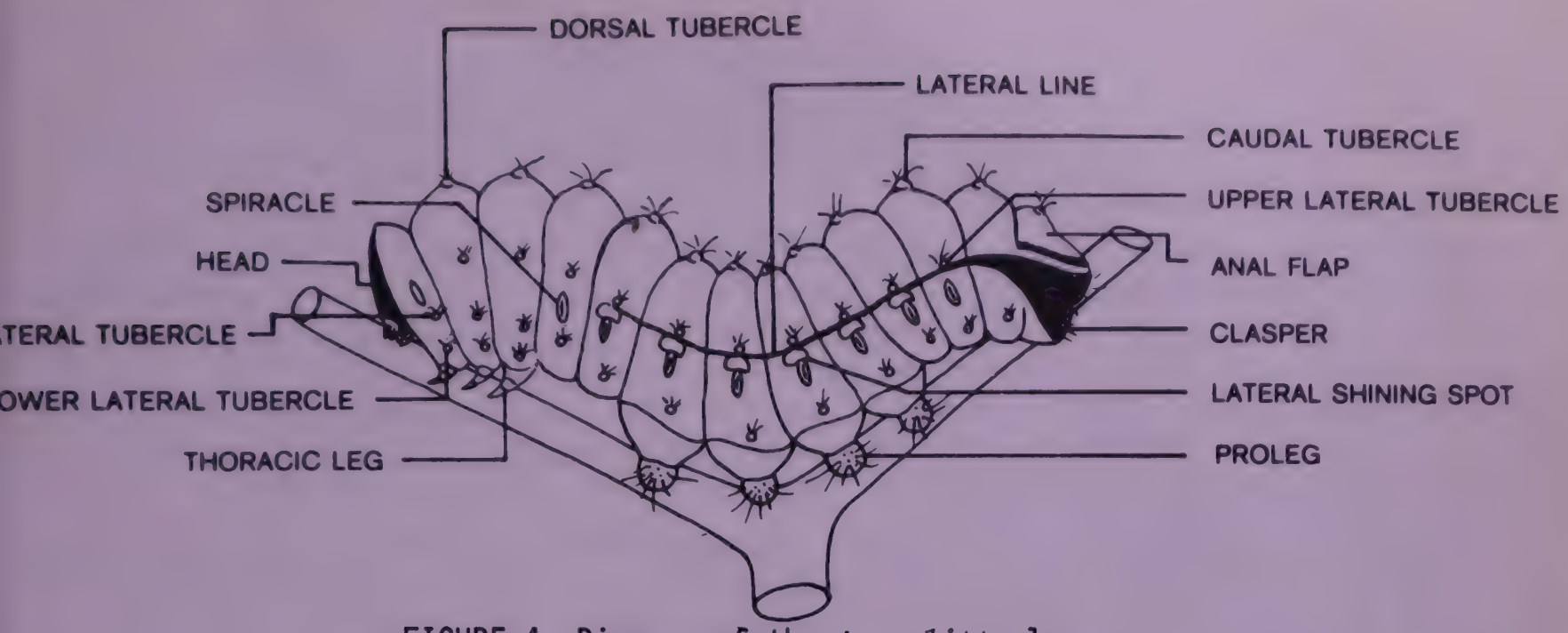


FIGURE 4. Diagram of the *A. mylitta* larva

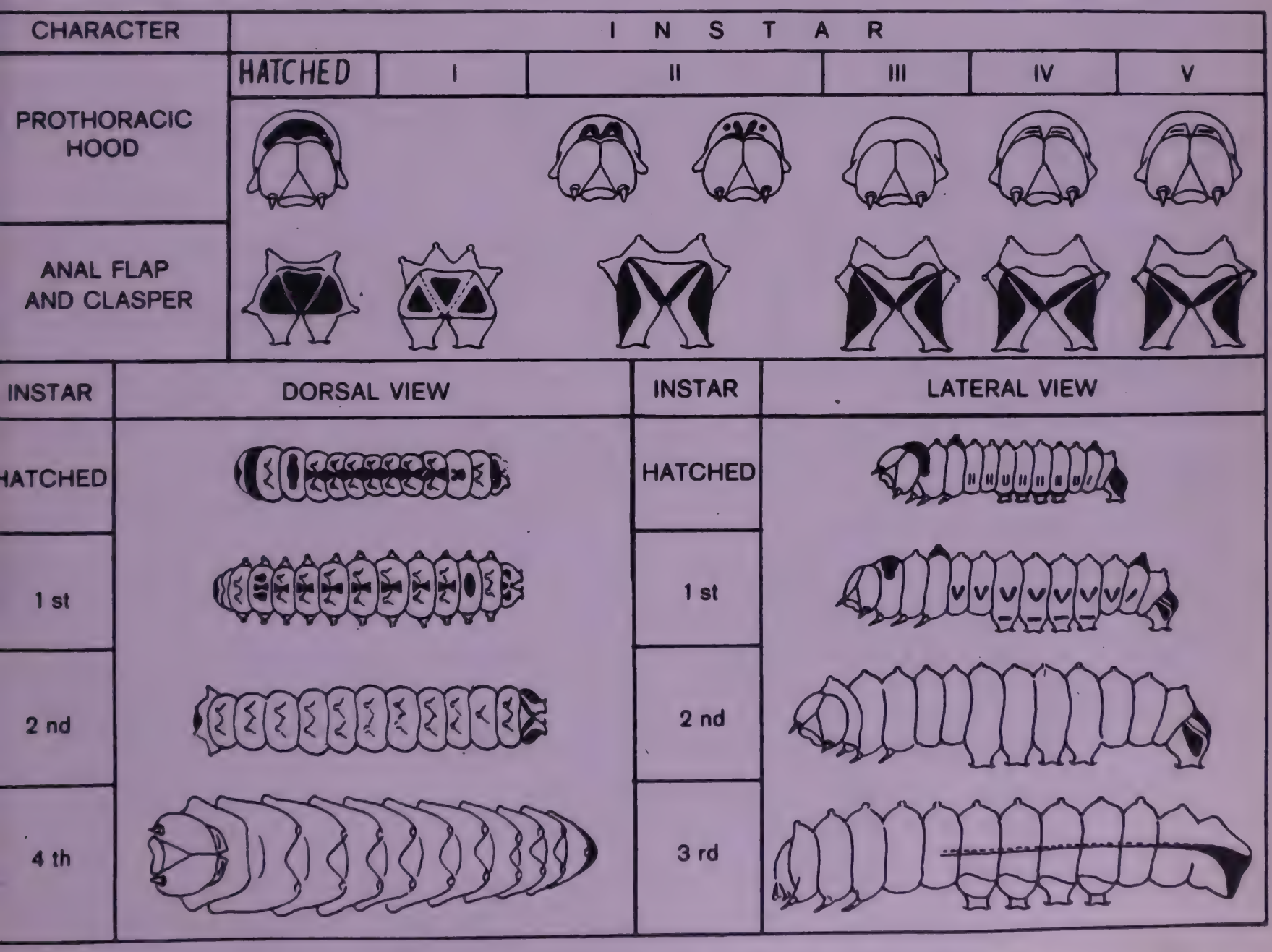


FIGURE 5. Developmental morphology of the *A. mylitta* larva

Some of the more important morphological features of the larva are discussed below:

Tubercles: In all stages the larva has five types of tubercles (Figure 7): dorsal (DT), upper lateral (ULT), lateral (LT), lower lateral (LLT) and caudal (CT). They are black in the first instar, orange red in the second and violet in the third to the fifth.

Hairs and setae: The hairs are white, minute and irregularly distributed over the body. The setae are of two kinds: body and tubercular. The white, pointed and long body setae are at the base of the dorsal tubercles of the first to eighth abdominal segments. The black tubercular setae, also pointed and long, are at the tip of the tubercles. The prothoracic hood carries structures similar to tubercular setae and corresponding in position to the dorsal tubercles (DT). The number and arrangement of setae vary according to type of tubercle, body segment and age of the larvae (137). The total number of tubercular setae remains constant until the third instar (Figure 78) and diminishes thereafter (502).

Shining spots: Silvery white lateral shining spots, either oval or triangular, appear during the third instar at the foot of upper lateral tubercles of the second to the seventh abdominal segment (Figure 8). Six regular (1:1–6:6) and thirty-eight irregular patterns have been recorded (138). Plain larvae are also common. Other shining spots are present at the base of the dorsal tubercles; these are brick red in green and yellow larvae and white in blue and almond-coloured larvae.

4.3 Pupa

The pupa is obtect adectious, having a well-defined, segmented body. The dark brown pupa measures about 4.5 x 2.3 cm and weighs 10.3 g. The ventral genital markings are on eighth and ninth abdominal segments (Figure 9).

4.4 Cocoon

The cocoon is single-shelled, pendent, oval, closed and reelable, having a hard non-flossy shell with fine grains (95). At the anterior end there is a well-formed dark brown peduncle with a ring at the distal end (Figure 10). The cocoons are generally yellow or grey. The females spin larger cocoons than the males (Table 6).

4.5 Moth

The moths exhibit distinct sexual dimorphism. The females are bigger (4.5 cm), with a distended abdomen and narrow bipectinate antennae 1.5 cm long. The males are smaller (4.0 cm), with a narrow abdomen and broad antennae. The females are polymorphic in colour, being grey and yellow, whereas the males are brown. Yellow and grey males and brown females are rare.

As the moths are a non-feeding stage, the mandibles and labial palpi are rudimentary (92). The terminal parts of the maxillae are modified into vestigial proboscises.

Wing — Male: The wing span is about 16 cm. The area of the fore wing is about 2 121 mm^2. The prominent postmedian line (PM) is red with a white line on its border (Figure 11). The antemedian line (AM) is usually black or dark brown and is bordered on the inside with a white line. In addition there is a black or dark brown oblique line (OL) with a white inner border.

The ocellus (OC; 70 mm^2), with a hyaline area (HA; 18 mm^2), is prominently positioned at the centre of the wing. The area between the ocellus and the postmedian vein is darker (DS).

The hind wing is about 1 584 mm^2, with an OC 50 mm^2 and HA 12 mm^2. The wavy, black Am is devoid of a white inner border. The DS is demarcated from the PM by a wavy margin. The OL is absent.

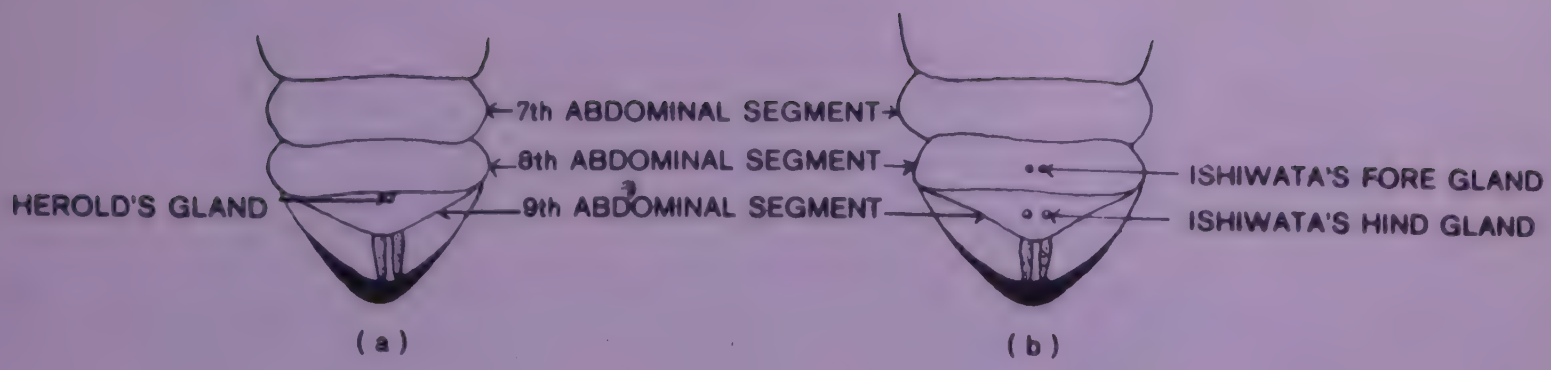


FIGURE 6. Sexual markings in the *A. mylitta* larva:

(a) male; (b) female

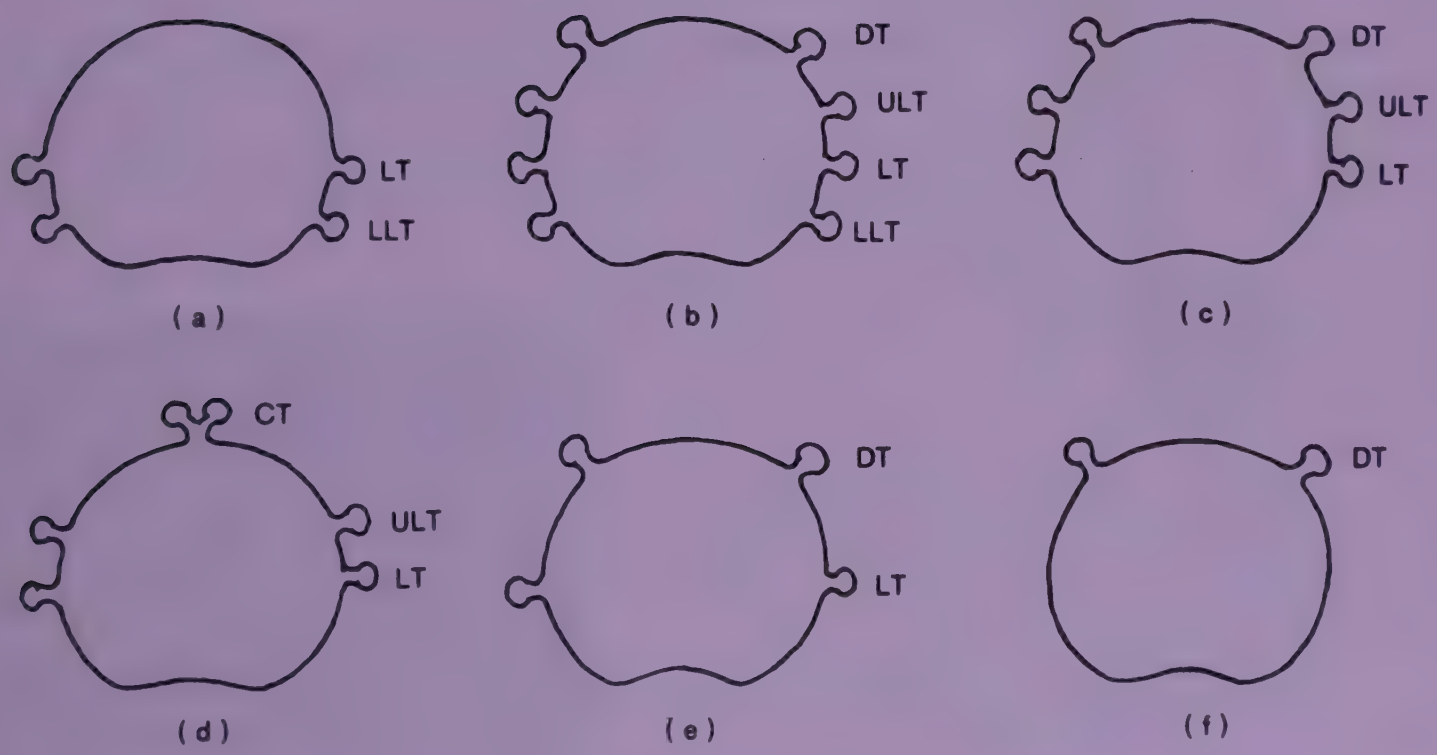


FIGURE 7. Arrangement of tubercles in *A. mylitta*:

(a) 1st thoracic,

(b) 2nd and 3rd thoracic segments:

(c) 1st - 7th abdominal,

(d) 8th abdominal,

(e) 9th abdominal, and

(f) 10th abdominal segments

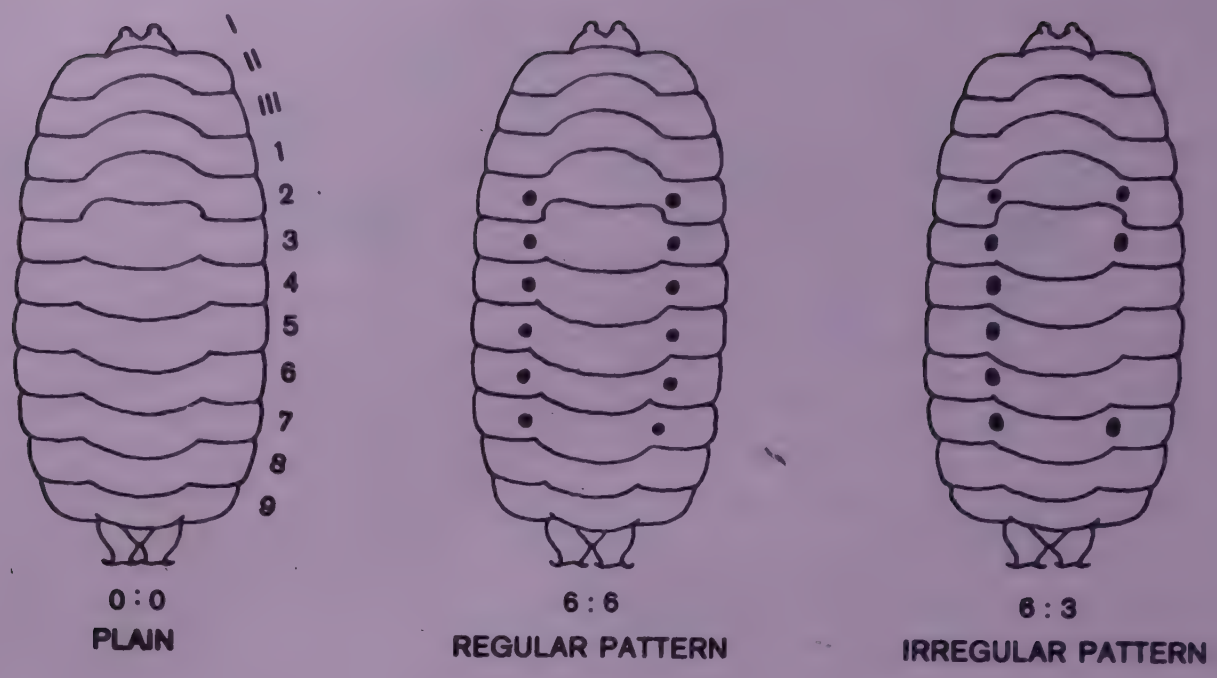


FIGURE 8. Regular and irregular patterns of lateral shining spots in *A. mylitta*

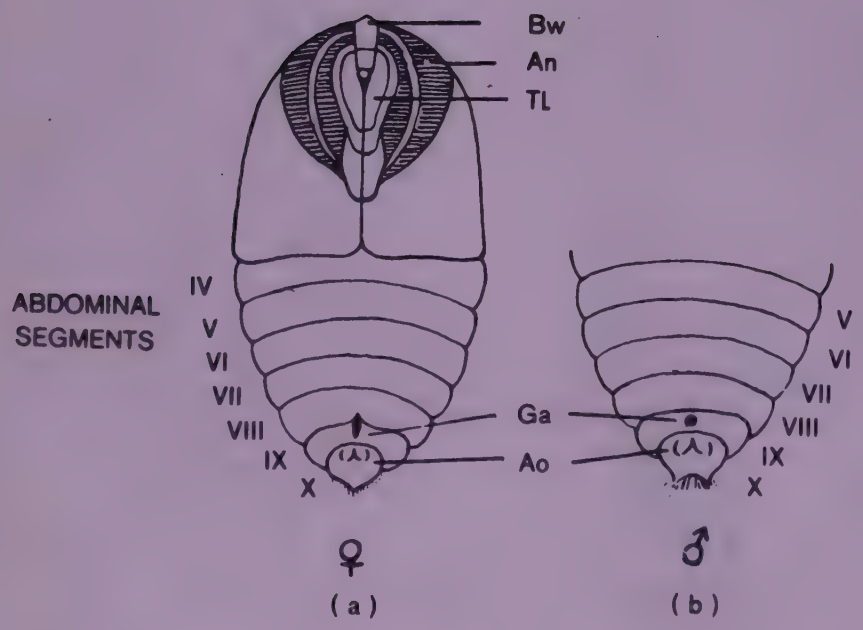


FIGURE 9. Pupa of *A. mylitta*:

(a) female; (b) male

Key: Bw = brain window, An = antenna,

Tl = thoracic leg, Ga = genital apperture

Ao = anal opening

FIGURE 10. Cocoon of *A. mylitta*

Table 6. Average quantitative characters of *A. mylitta* (Daba) cocoons

Sex	Cocoon size (cm)	Peduncle length (cm)	Cocoon volume (cc)	Cocoon weight (g)	Shell weight (g)	Shell ratio (%)
Male	5.1 x 2.9	4.0	28.6	11.1	1.4	14
Female	5.5 x 3.3	5.7	29.5	14.2	1.9	12

Female: The wing span is about 18 cm. The fore wing is about 2 350 mm² (Figure 12). The PM is similar to that of the male, and the AM is variable in colour; grey, deep yellow, brown or black. The OC is about 85 mm² in area and the HA 25 mm². The hind wing covers an area of about 1 850 mm², an OC 25 mm² and HA 16 mm².

The colour pattern of the ocelli is the same in both male and female moths (Figure 13).

Wing scales: The wing scales are generally conical or narrow and bristle like with up to seven spines of different lengths (Figure 14).

Wing venation: The principal veins of the fore wing are designated costa (C), sub-costa (Sc), radius (R_1, R_4 R_5), media (M_1–M_3), cubitus (Cu_1, Cu_2), and anal (An_1, An_2). In addition there are weak veins such as the media bases (A_1, A_2), the median crossvein (Mc) and the third anal vein (An_3). Mc is wavy and touches neither A_1 nor A_2 (Figure 15). In the hind wing R_1 and Sc merge, and R_4 and An_3 are absent.

Genitalia: The last four abdominal segments (7–10) are modified to form the genitalia (Figures 16, 17). In *A. mylitta* unlike other members of the family, neither socii nor valvulae and valvifers are present in the males and females (171). Furthermore, the presence of accessory harpes in the males is yet another departure from the general Lepidopteran pattern. Moths with both male and female genitalia are rare (168).

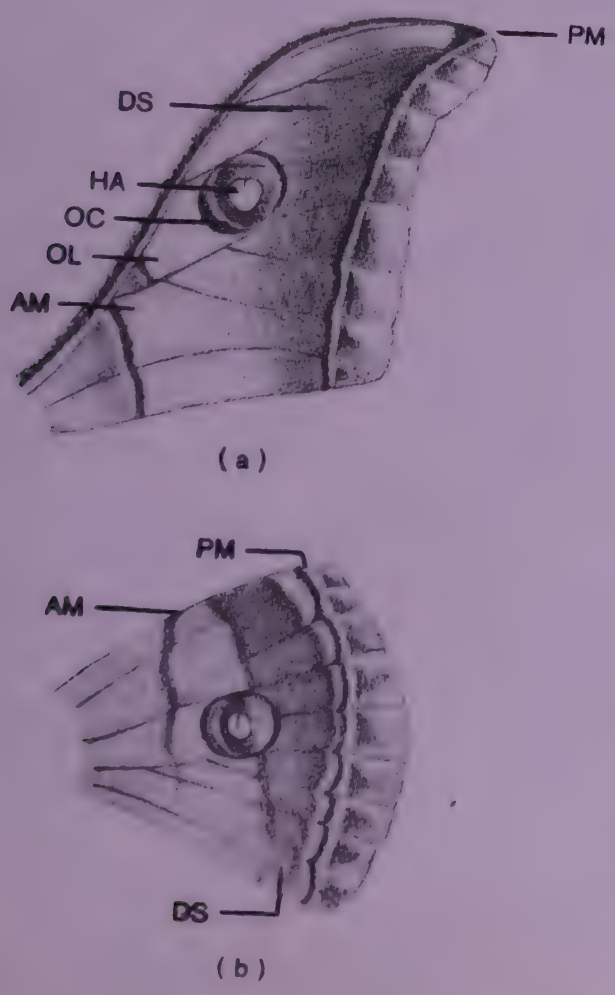


FIGURE 11. (a) Fore wing and (b) hind wing of the male moth of *A. mylitta*, showing colour pattern

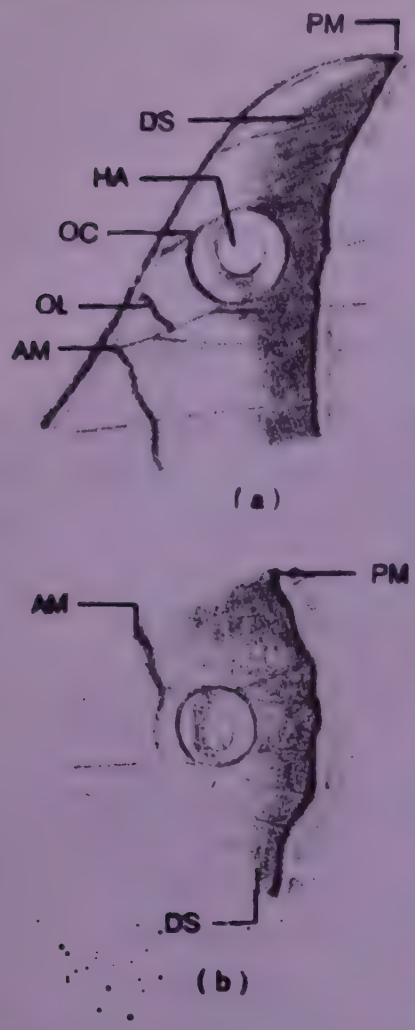
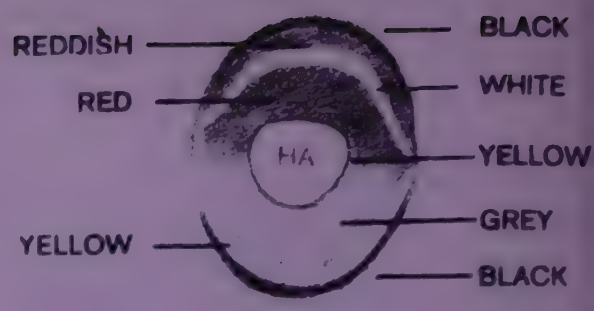


FIGURE 12. (a) Fore wing and (b) hind wing of the female moth of *A. mylitta*

FIGURE 13. Colour pattern of the ocellus of the *A. mylitta* moth



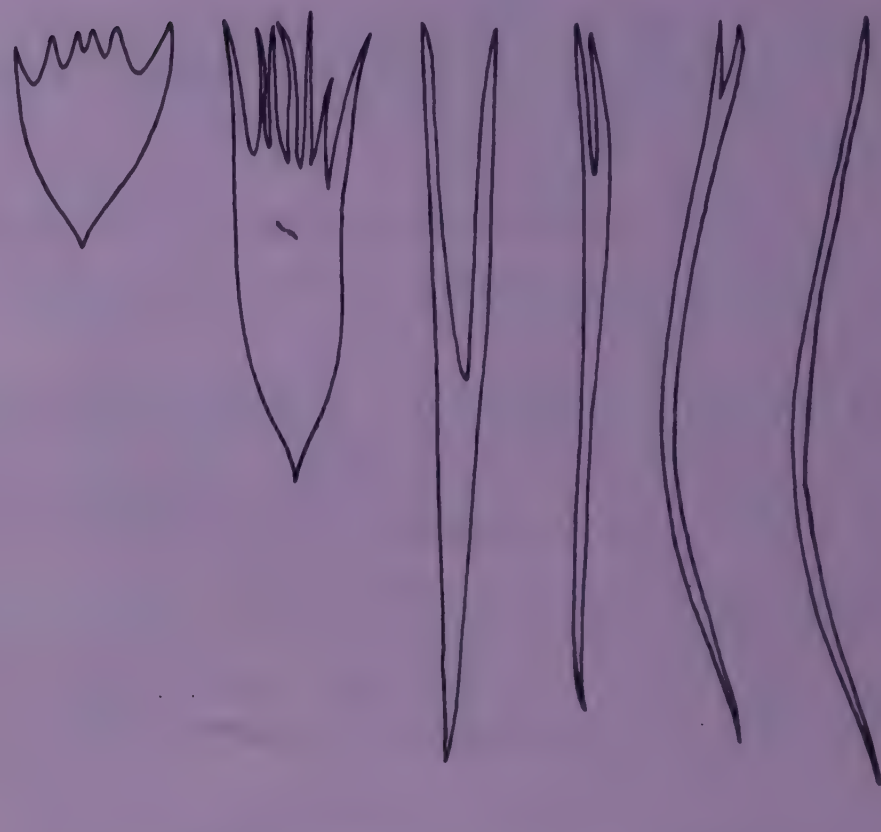


FIGURE 14. Wing scales of *A. mylitta*

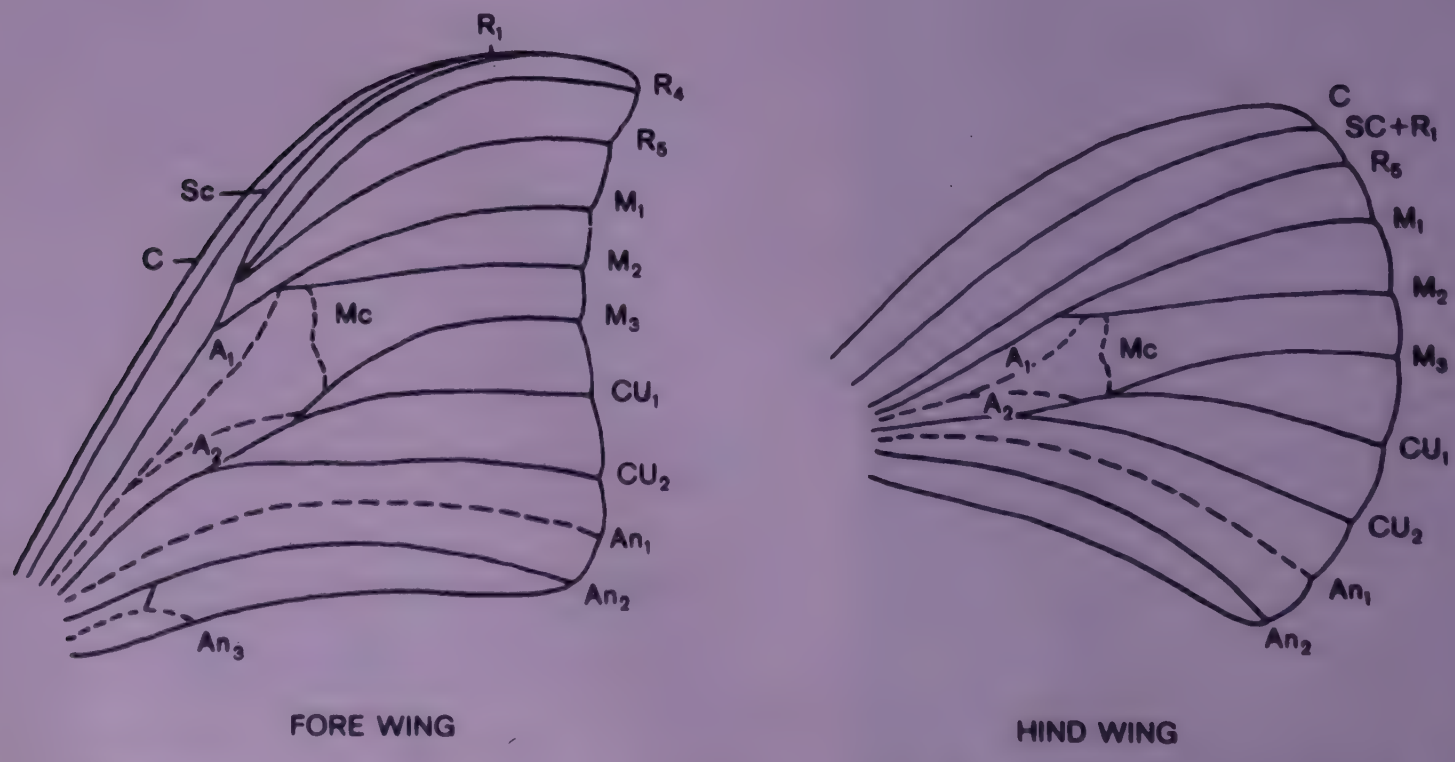
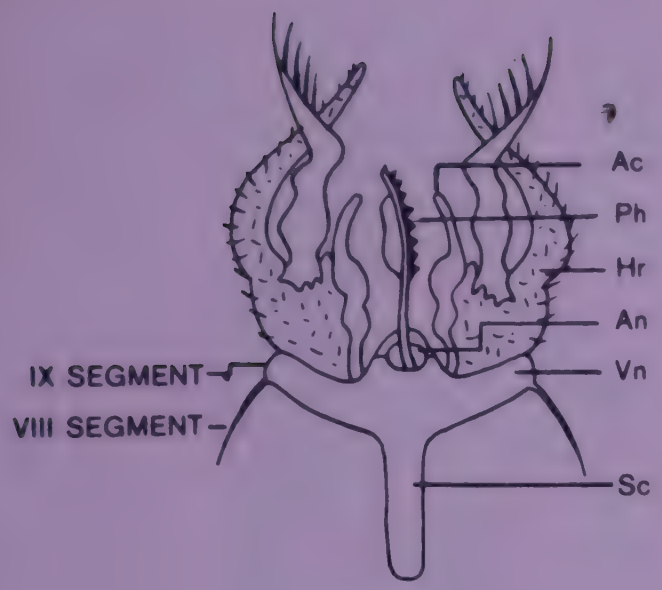
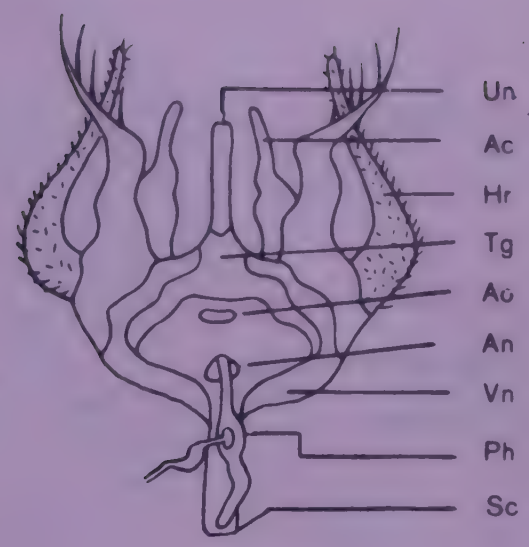


FIGURE 15. Wing venation of *A. mylitta*: (a) fore wing; (b) hind wing



(a)



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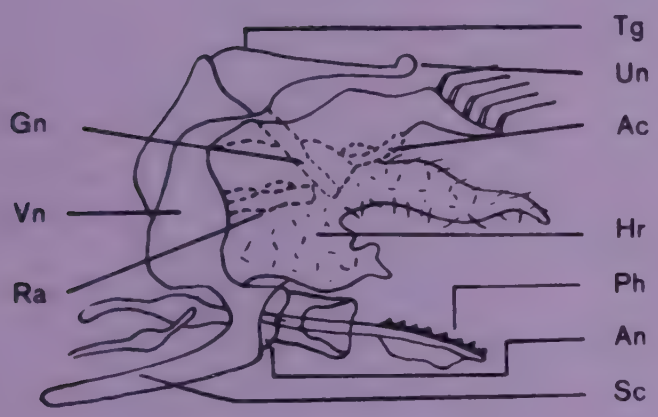

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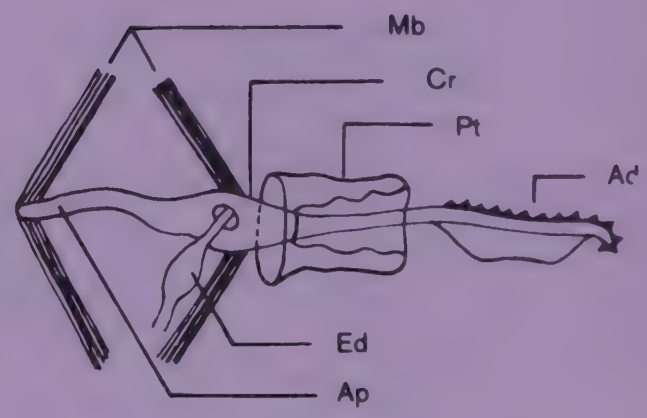


(d)

FIGURE 16. Genitalia of the male moth of *A. mylitta*:

(a) ventral view; (b) dorsal view; (c) lateral view; (d) dorsal view

Key: Ac = accessory harpes, Ad = aedeagus, An = anellus,

Ao = anal opening, Ap = apodem, Cr = cornua,

Ed = ejaculatory duct, Gn = gnathos, Hr = harpes,

Mb = muscle band, Ph = phallus complex, Pt = phallotheca,

Ra = rudimentary anus, Sc = saccus, Tg = tegumen,

Un = uncus, Vn = vinculum

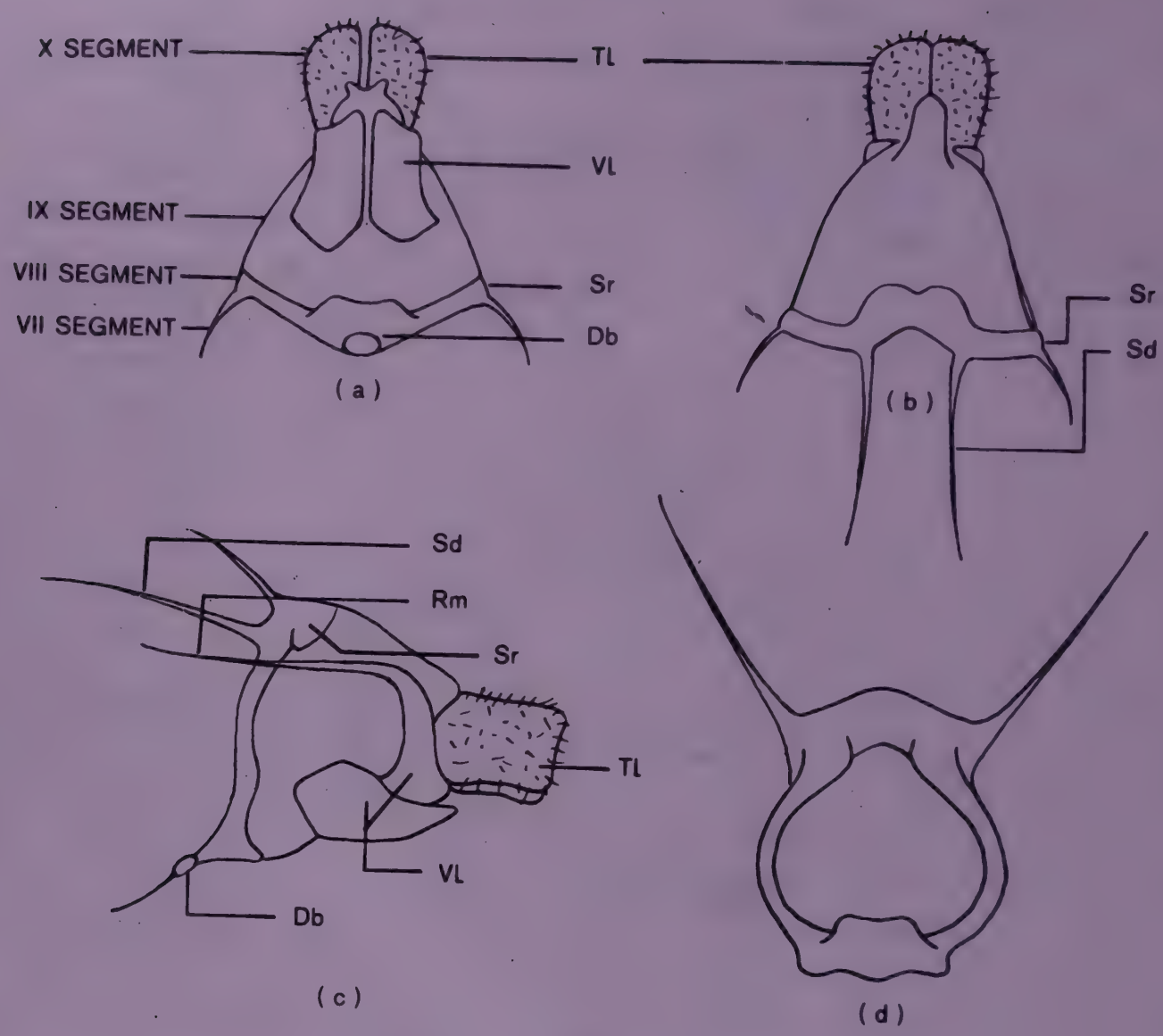


FIGURE 17. Genitalia of the female moth of *A. mylitta*:

(a) ventral view, (b) dorsal view
(c) lateral view, (d) sclerite ring

Key: Db = opening of ductus bursa, Rm = triangular sclerite rod, Sd = sclerite rod, Sr = sclerite ring, Tl = terminal lobe, Vl = valvula

Chapter 5
ANATOMY

5.1. Digestive system

The digestive system is well developed and functional in the larva as this is the only feeding stage in life cycle of the insect. The alimentary canal consists of three primary divisions: stomodaeum, mesenteron and proctodaeum (Figure 18a). The stomodaeum is separated from the mesenteron by a cardiac sphincter, and the proctodaeum from the mesenteron by a pyloric sphincter. These sphincters check the reverse flow of food material. Enteric caeca are absent. Two prominent muscle bands extend mid-dorsally throughout the proctodaeum. The six rectal papillae are well developed. In the nonfeeding stages of pupa and moth the alimentary canal is greatly reduced (Figure 18b).

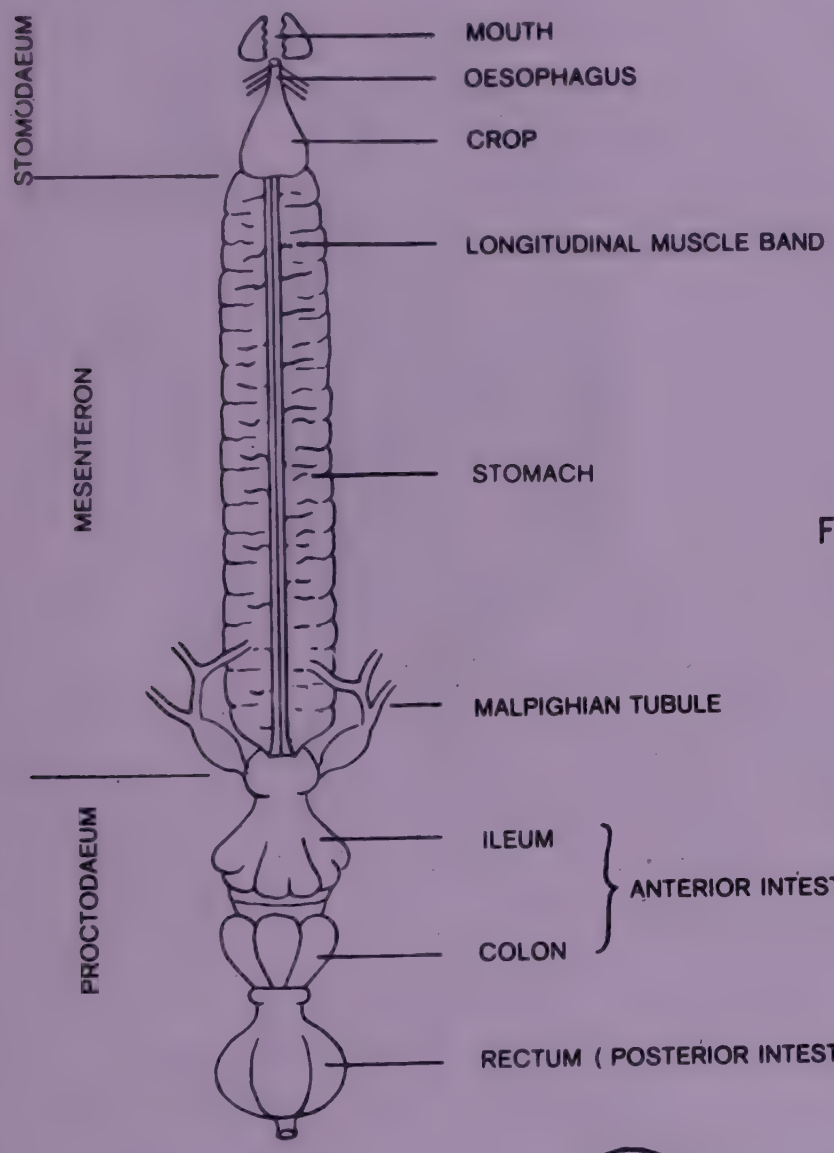


FIGURE 18a. Alimentary canal of the *A. mylitta* larva

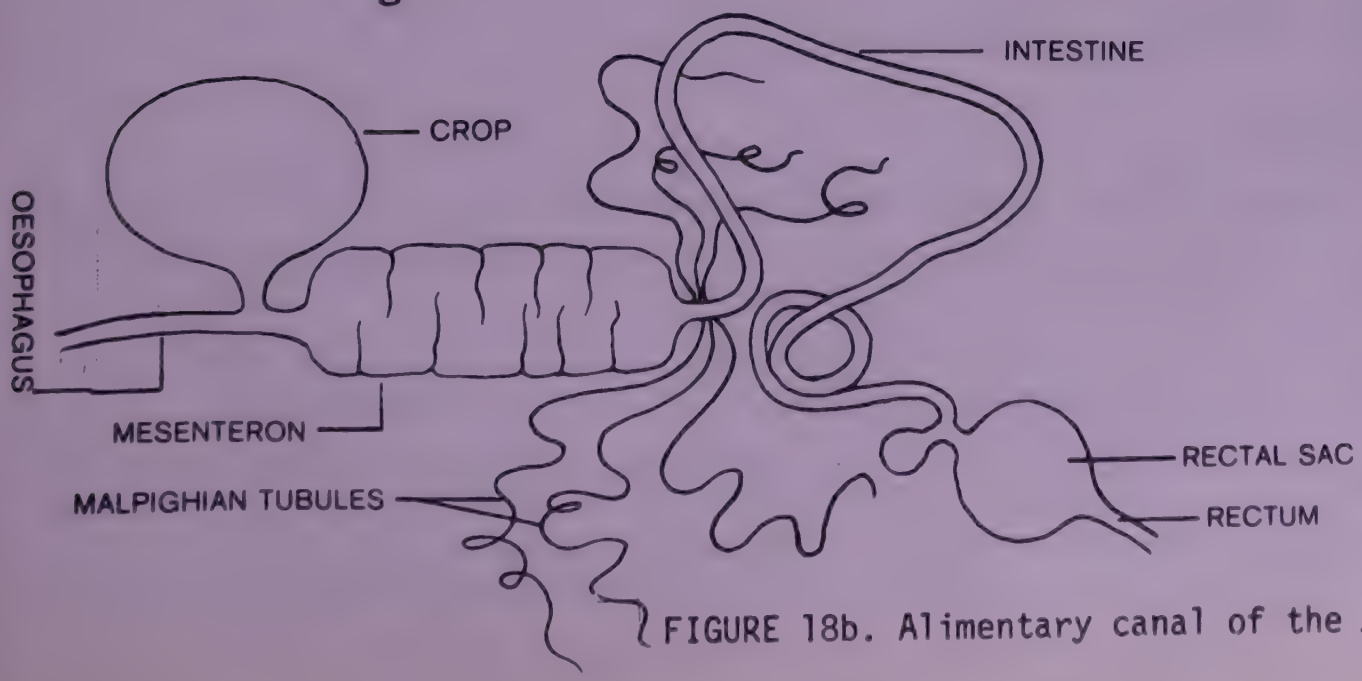
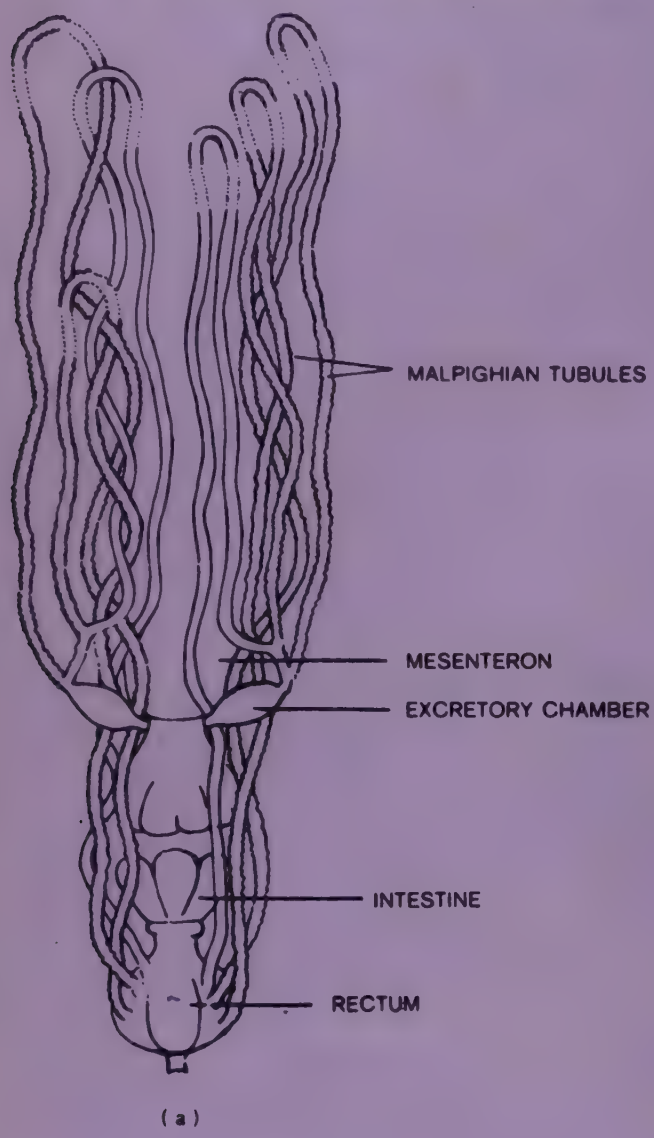


FIGURE 18b. Alimentary canal of the *A. mylitta* moth

5.2 Excretory system

The excretory system is of the cryptonephric type. The malpighian tubules remain structurally similar in all stages of the life cycle. Originating at the junction of the mesenteron and the ileum, they are typically long, slender and extremely convoluted; the terminal portions are intimately associated with the rectal wall (Figure 19a). The tubules, except for the dorsal one, bear globular structures, called diverticulae, all along their length, imparting a striated appearance (Figure 19b). Two of the malpighian tubules on each side are light yellow, and the other is translucent.



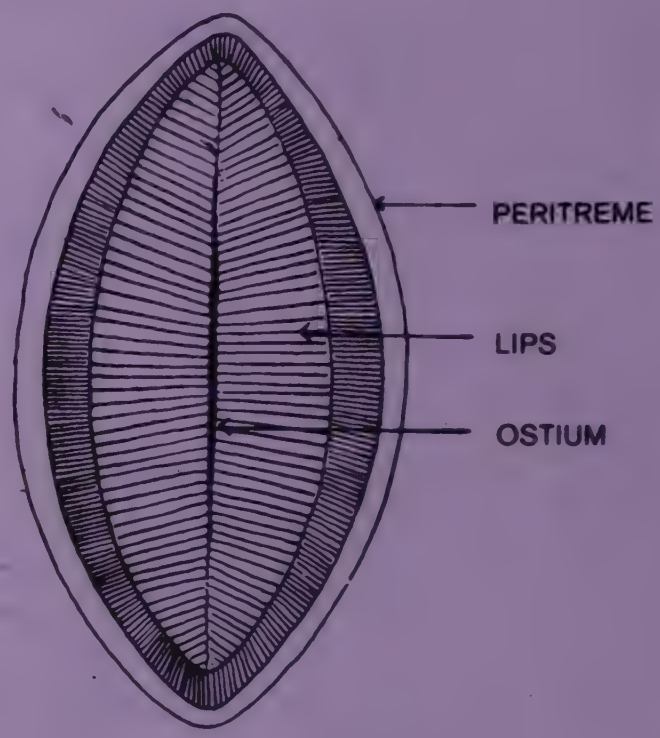


FIGURE 20. Spiracle of the *A. mylitta* larva

FIGURE 19. (a) Excretory system

of the *A. mylitta* larva;
(b) a magnified portion of malpighian tubule

5.3 Respiratory system

The larval tracheal system is of the peripneustic type (Figures 20, 21). Each spiracle is formed of a pair of lips, or sieve plates, surrounded by a rimlike structure (peritreme). The exterior opening (ostium) of the spiracle leads into a cavity (atrium) containing the closing apparatus.

The tracheal system consists of a pair of lateral trunks extending longitudinally along the body wall. These are connected with their respective spiracles by a short spiracular trachae. The principal abdominal branches emanate from the lateral trunks. A number of visceral trachea forming a "tracheal bush" arise from the lateral trunks near each spiracle and invade principally the wall of the alimentary canal. A ventral transverse trachea connects the two tracheal bushes in each segment. In the thoracic region the trachea are quite differently arranged, because they supply not only the thoracic segments but also the head.

The adult tracheal system is very similar to that of the larva, but it communicates with the exterior by means of two pairs of thoracic spiracles and seven pairs of abdominal spiracles (in the first seven segments).

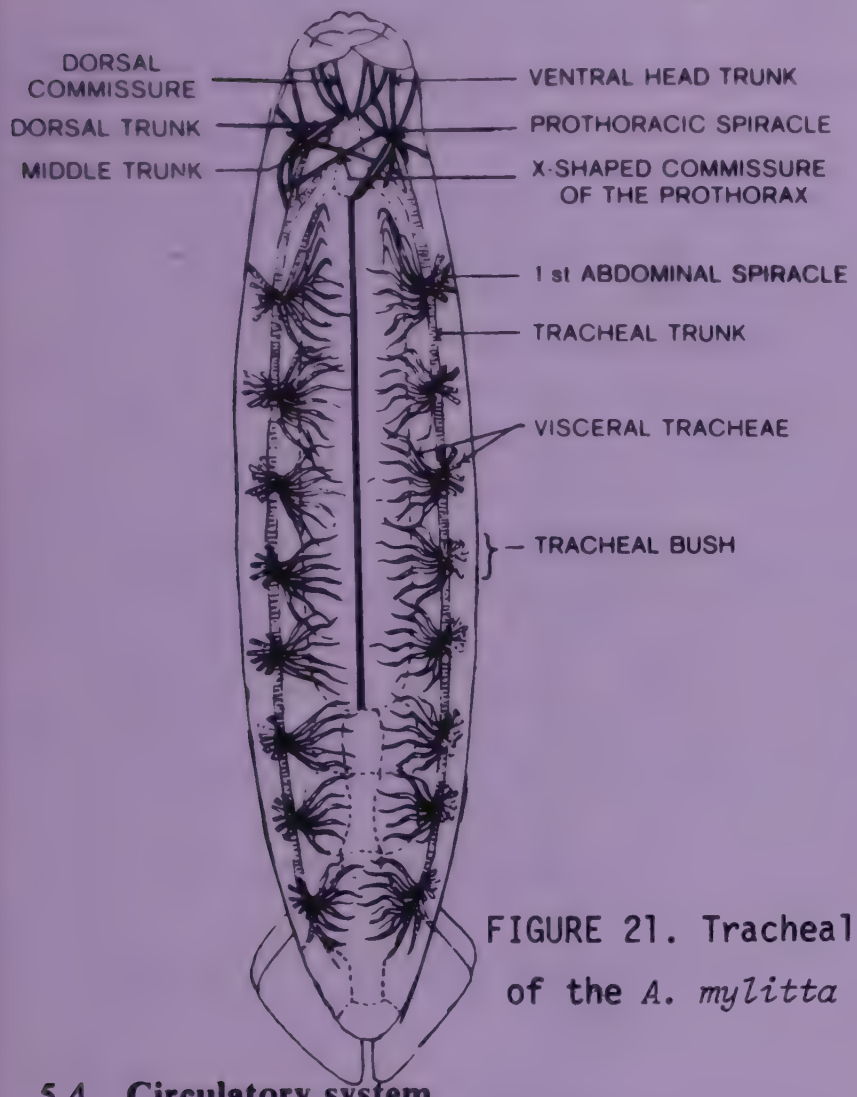


FIGURE 21. Tracheal system of the *A. mylitta* larva

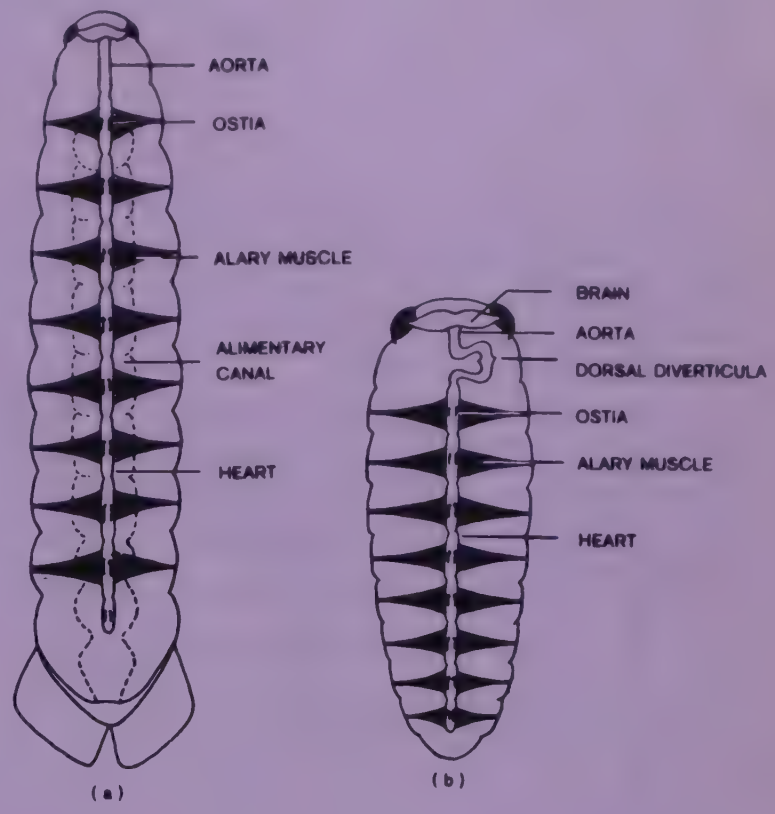


FIGURE 22. Circulatory system of the *A. mylitta* (a) larva and (b) moth

5.4 Circulatory system

The circulatory system is of the open type. In the larva the dorsal blood vessel is a straight tube differentiated into the posterior heart and the anterior aorta (Figure 22a). The heart exhibits symmetrical cardiac swellings (chambers) corresponding to the body segments (from the third thoracic to the ninth abdominal). Each chamber opens into the haemocoel through paired dorsolateral openings, or ostia. The aorta is a simple, slender, unperforated tube that continues forward from the first chamber of the heart into the head. In the adult the aorta makes a large bend upward in the mesothorax and terminates behind the brain (Figure 22b).

The blood flows backward in the body cavity and forward in the dorsal blood vessel. It enters the heart mainly through the lateral ostia of the last abdominal segment and is discharged in the head region.

5.5 Nervous system

The nervous system can be divided into three major divisions: central, visceral and peripheral.

Central nervous system: The CNS of the larva comprises the brain, or supra-oesophageal ganglion, the sub-oesophageal ganglion and the ventral nerve cord (Figure 23a). The brain supplies the nerves of the facial ocelli, the antennae, the frontal ganglion and the labium. The sub-oesophageal ganglion is connected with the brain by circumoesophageal commissures and supplies nerves to the mandibles, the maxillae, the hypopharynx, the labium and the silk gland. The ventral nerve cord is

5.7 Silk glands

The silk glands are the most conspicuous part of the larval anatomy (Figure 25). Morphologically the glands are divided into two distinct regions. The narrow proximal region is the excretory duct, whereas the thick, long and highly convoluted distalregion is secretory. The common excretoryduct (conduit) opens into the silk press. A short directing tube anterior to the silk press terminates at the tip of the spinneret. The dorsal wall of the silk press is deeply invaginated into the lumen, in which there are two pairs of muscle bands.

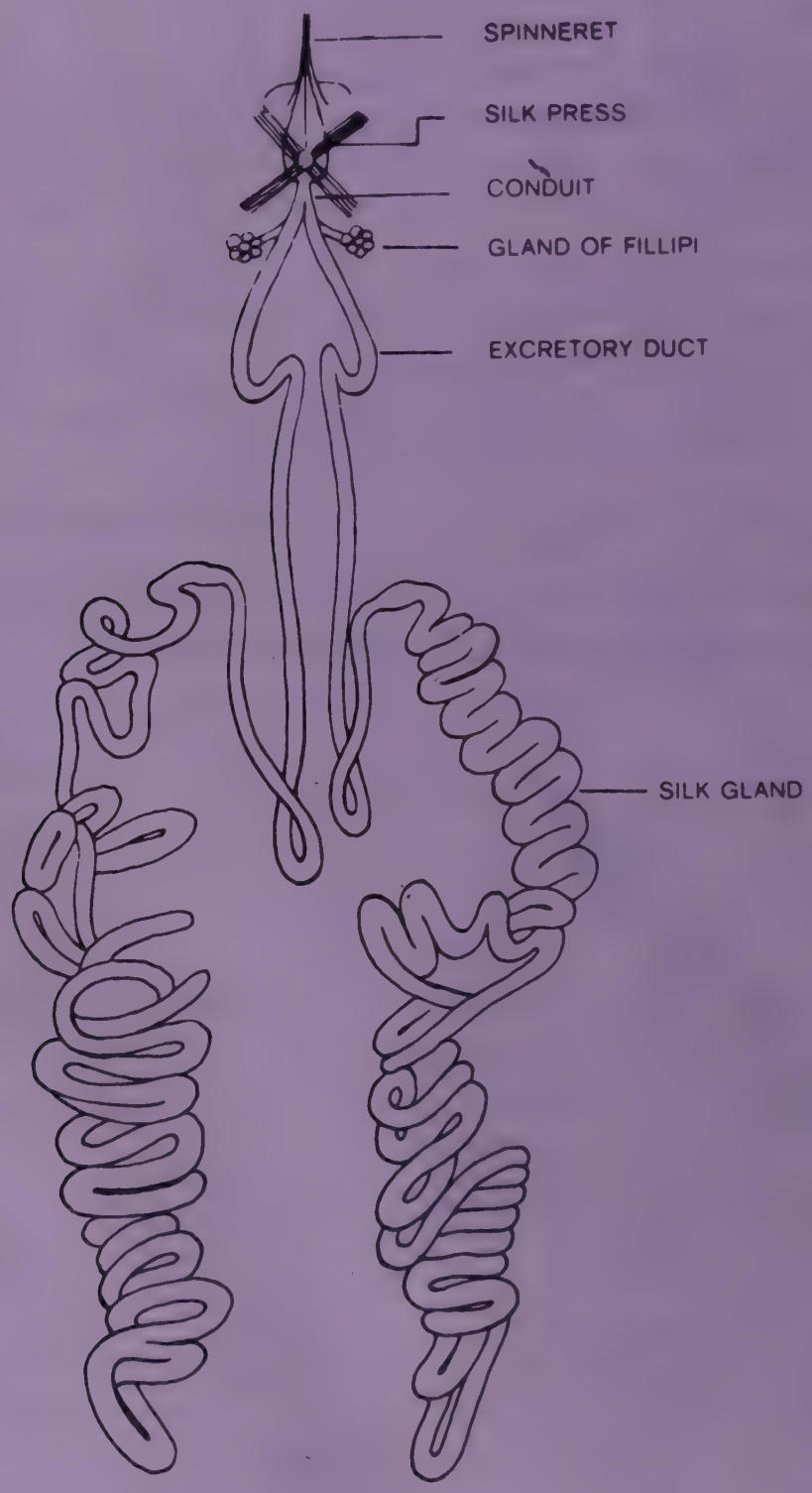


FIGURE 25. Silk glands of *A. mylitta*

Anatomically *A. proylei, A. pernyi, A. assamensis, A. mylitta* and *P. ricini* are highly similar, as taxonomically they are closely related; however, some minor dimensional variations are observable.

Chapter 6

ARBORICULTURE

Non-mulberry silkworms are polyphagous. Nevertheless, certain plants have been observed to yield a better crop of cocoons with superior technological properties. These are referred to as primary food plants, while the others are known as secondary food plants.

6.1 Food plants

Primary food plants: Eight primary food plants for tropical tasar silkworms have been reported (64, 68, 139): *Terminalia tomentosa* W. & A. (asan; Figure 26), *T. arjuna* W. & A. (arjun; Figure 27), *Shorea robusta* Roxb. (sal; Figure 28), *Lagerstroemia parviflora* Roxb, (sidha) *L. speciosa* Pers. (jarul), *L. indica* Linn. (saoni), *Zizyphus mauritiana* Lam. (ber) and *Hardwickia binata* Roxb. (anjan).

FIGURE 26. *Terminalia tomentosa* (asan)

FIGURE 27. *Terminalia arjuna* (arjun)

Secondary food plants: Of the more than two dozen secondary food plants so far reported (68, 157), the most important are *Terminalia chebula* Retz. (haritaki), *T. belerica* Gaertn. (bahera), *T. catappa* L. (jangli badam), *T. paniculata* Roth. (kinjal), *Anogeissus latifolia* Wall. (dhaunta), *Syzygium cumini* (L.) Skeels (jamun), *careya arborea* Roxb. (kumbi) and *Shorea tailura* Roxb.

6.2 Distribution

The food plants of tropical tasar silkworms grow luxuriantly at low altitudes (0–600 msl) between about 40^0 north and south latitudes (Figure 29).

Table 7 lists the areas in which the primary food plants are found.

FIGURE 28. *Shorea robusta* (sal)

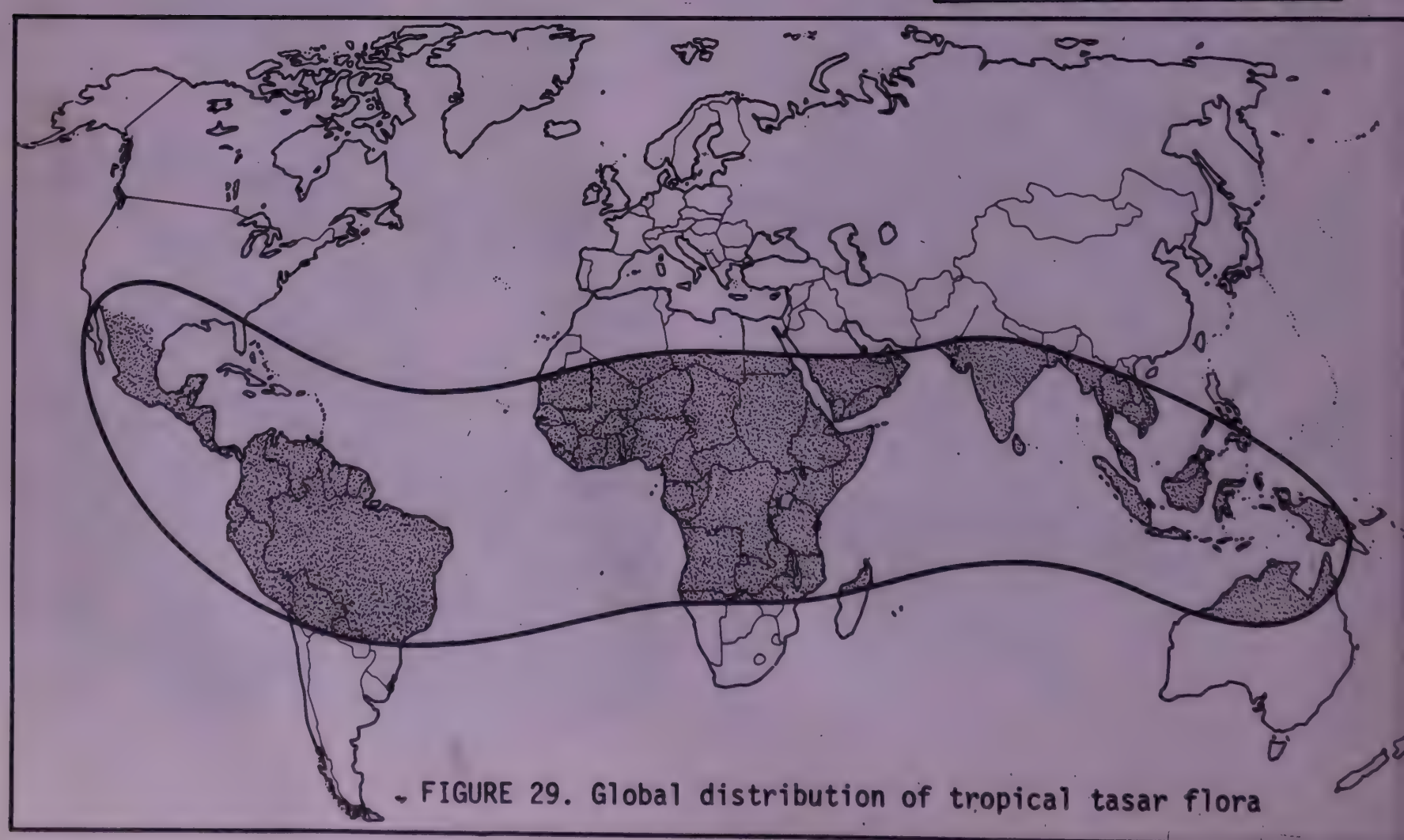


FIGURE 29. Global distribution of tropical tasar flora

Table 7. Global distribution of parimary food plants of tropical tasar

Food plant	Distribution
Terminalia spp.	India, Nepal, Burma, Laos, Khmer, Sri Lanka, Indonesia, Malaysia, New Guinea, Australia, Africa
T. tomentosa var. ∝-*nepalensis* Th.	North India up to Nepal
T. tomentosa var. β-*typica* Clarke	Central India
T. arjuna	Central and Eastern India
Shorea robusta Roxb.	Throughout the tropics and subtropics
Lagerstroemia spp.	India, Sri Lanka, China, Vietnam, Malaysia, Indonesia, Australia
L. parviflora Roxb.	Base of the western Himalayas and south of Indo-Gangetic plain
L. parviflora var. *majuscula*	Central India.
L. parviflora var. *benghalensis*	Nepal, Burma, northeastern India
L. speciosa Pers.	India, Vietnam, Malaysia, China, Sri Lanka
Zizyphus mauritiana Lam.	India, Afghanistan, Malaya archipelago, China, Australia
Hardwickia binata Roxb.	Tropics, particularly Africa and western peninsular India

6.3 Taxonomy

The taxonomical aspects (51, 56) of the two important genera of tropical tasar flora are enumerated in the following paragraphs.

Terminalia Linn.

Order: Myrtales; Family: Combretaceae.
Habit: large tree
Leaf: simple, subopposite or alternate,
exstipulate, often with glands on the petiole or near the underside of the midrib base.

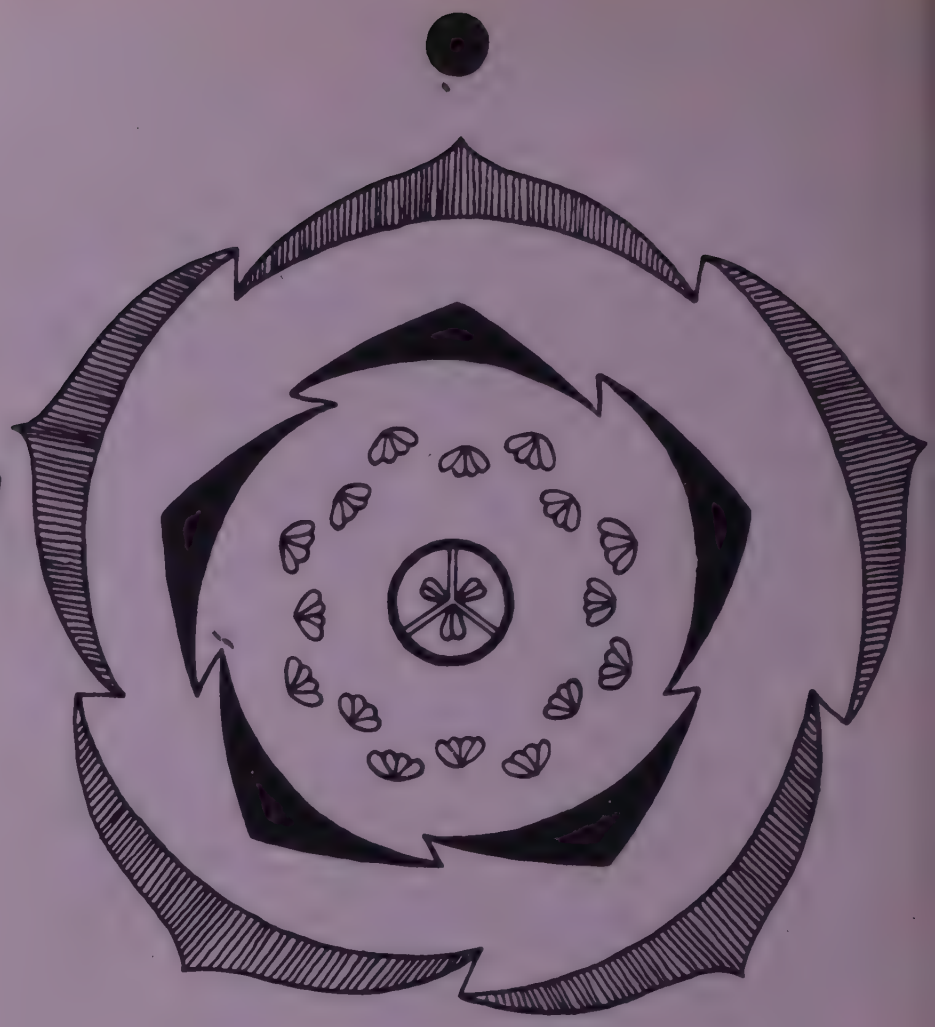
Flower: small, dull yellow, sessile, raceme spikes occasionally panicled, bisexual, incomplete (Figure 30); calyx — sepals, five, petaloid, valvate; corolla — petals, none; androecium — stamens, ten (five plus five), inserted on the calyx tube; gynaecium — ovary, one-celled, inferior, two or three ovules, pendulous, long and simple style.

Fruit: coraceous drupe, variable size (3–6 cm long), ovoid, often winged (two to five wings).

Seed: exalbuminous, oily, fleshy.
Sprouting: March and April.

F.F. ⊕ ♀♂ $K_{(5)}\,C_{0}\,A_{5+5}\,G_{\underline{1}}$

FIGURE 30. Floral diagram of the genus *Terminalia*



F.F. ⊕ ♀♂ $K_{(5)}\,C_{(5)}\,A_{\infty}\,G_{(\underline{3})}$

FIGURE 31. Floral diagram of the genus *Shorea*

Shorea Roxb..
Order: Parietales;
Family: Dipterocarpacea
Habit: large resinous and subdeciduous tree.
Leaf: simple, alternate, stipulate, entire or subrepand.

Flower: regular, bisexual, arranged in axillary or terminal lax cymose panicles, subsessile (Figure 31); calyx — tube, short, five–lobed, adnate to the receptacle, imbricate; corolla — petals five, pale yellow, much longer than the calyx, twisted; androecium — stamens fifteen or many, much shorter than the petals, hypogynous or half perigynous; gynaecium — ovary three–celled, filiform style, entire or three–toothed stigma.

Fruit: capsular or nutlike, edible, usually winged.

Seed: exalbuminous, fleshy, cotyledons.

Sprouting: February and March.

6.4 Vegetative propagation

Seedling propagation of tasar food plants, though slow, is common practice, as they cannot be easily propagated asexually. Asexual propagation has been successfully achieved, however, in some food plants.

Cuttage: The propagation of hardwood by cuttage is rather difficult. To a limited extent, *T. arjuna* stem cuttings can be induced to root in a special type of mist chamber. *L. indica* has been propagated by treating cuttings 1.0–1.5 cm thick and 18–20 cm long with Seradix B_2/ B_3 and inserting them in soil or a porous rooting medium. It is also possible to propagate *Z. mauritiana* with the help of root-inducting hormones (59).

FIGURE 32. A rooted stem cutting of *L. indica*

Grafting and buddage: *T. arjuna* and *S. cumini* can be propagated by approach grafting, or inarching, and *Zizyphus* by cleft grafting (175). Both the Forkert budding and T-budding methods can be used on *S. cumini*, and only the latter on *Z. mauritiana* (175).

Layering: *T. arjuna* (176) and *Z. mauritiana* (59) can be propagated by air layering. A ring of bark about 3 cm long and 1.5 cm thick is removed from a twig. The debarked area is treated with Seradix B_2/ B_3, covered with "gootee" (FYM and soil in equal parts, plus some moss) and wrapped with polythene. After sufficient rooting has occurred (within 4–6 weeks), the portion of the twig below the layer is cut off and transplanted. It is also possible to perpetuate *T. arjuna* by ground layering.

6.5 Plantation

Economic plantation: Tasar food plants as found in nature are tall trees irregularly distributed in forests or on bunds of paddy fields. Because of the consequent difficulties of overseeing the larvae, mortality from pests and diseases is high, particularly during the early instars. As the foliage consumption of larvae until the third instar is only 15–20%, this problem can be solved effectively by rearing them in limited systematic plantation (33). Economic plantations of *T. arjuna* (Figure 33) from 2 to 3 year saplings closely spaced (1.2 x 1.2 m) become suitable for rearing within 3 years. The higher density of trees per unit area yields over 17 metric tons of foliage/ hectare. Furthermore, being of the medium bushy type with overlapping twigs, tasar food plants can be rainfed and grow in submarginal soils, which are widespread in India (about 42 million ha) and in other developing countries (163).

FIGURE 33. An economic plantation of *T. arjuna*

Block plantation: consists in the setting aside of forest patches having a high concentration of primary food plants for systematic rearing operations. The number of tasar food plants in such areas should be increased gradually. These plantations can be gainfully utilized for advance-stage rearing of larval populations initiated on economic plantations (Chapter 9).

6.6 Transplanting

The pits (30 cm^3) are filled with a mixture of soil, 10–20 kg of FYM/compost and 100–200 g each of "karanj" cake, bone meal, wood ash and aldrin dust (5%). Transplanting should be done in June and July. A basin should be prepared around the base of each transplant. Transplanting is especially necessary in economic and block plantations.

6.7 Training

The tasar food plants have a tendency to grow tall; but for effective rearing, plants about 2–3 m tall with rich foliage and a well-spread crown are ideal. Of the three common training systems — central leader, open centre and modified leader — the last is recommended for economic plantation. In this case the central axis is not allowed to grow indefinitely. In natural plantations it is desirable to pollard the trees 1–2 m above the ground level in March and April every 3 to 4 years.

6.8 Plant protection

Controls against some of the important pests, diseases and mineral deficiencies are given in Table 8. In view of the toxic effects, it is advisable to observe an adequate safety period (1 to 2 weeks) after every spraying or dusting.

Table 8. Controls against pests, diseases and mineral deficiencies

Pest/disease	Damage	Control
Stem borer (*Sphenoptera konbierensis*)	Larvae bore into *T. arjuna* and *T. tomentosa* shoots killing the branches.	Plugging with cotton soaked in petrol/kerosene oil/EDCT and pasting with mud. Light traps for adults.
Gall fly (*Phylloplecta hirsuta* and *Trioza* spp.)	Young flies produce ugly galls on *T. arjuna* and *T. tomentosa* foliage.	Dimecron (0.03%) or Rogor (0.5%) spray
Termites (*Microtermes, Odontotermes* and *Trinervitermes* spp.)	Attack the food plants at all stages of growth.	Termitorium should be unearthed and destroyed by pouring crude oil emulsion/aldrin (30% E.C.) emulsion. Aldrin dust (5%) should be mixed with soil at 20 kg/ha.
May–June beetle (*Anomala* spp.)	Feeds on leaves of food plants	Optimum tillage operations and soil application of aldrin dust (5%) at 20 kg/ha.
Stem canker	Tumorlike growth on *T. tomentosa* twigs increases in size and bursts into ugly ulcers	Heavy pruning and burning of infested twigs, dressing of cut ends with Bordeaux paste after pruning, spraying with Zincop (0.3%).
Leaf curl	Crinkling of leaf surface in *T. tomentosa* and *T. arjuna.*	The same as for stem canker.
Root rot (*Gauoderma lucidum*)	Affected roots (T. *tomentosa, S. robusta*) decompose and die. Poorly developed lateral roots become long spreading with age and spread infection.	Burning of dead plants. Digging of isolation trenches (1.5x0.7x0.3m) to isolate healthy from infected tracts
Molybdenum deficiency	Marked malformation of leaves and poor head formation.	Liming of acid soils and application of ammonium molybdate at 1.5–2.0 kg/ha.
Zinc deficiency	Green lateral leaf veins and mottling	Spraying with Zincop (0.3%) or Punjab mixture.

6.9 Cytology

It has been claimed (127) that the genus *Terminalia* is monobasic (n=12). Similarly, n=13 has been recognized in *C. arborea* (108). *S. cumini* and *L. indica* show a remarkable degree of karyological plasticity, ranging from n=11 (124) to n=33 (16) in the former and from n=16 (37) to n=25 (125) in the latter. These higher numbers have evolved either by simple euploidy or by amphidiploidy accompanied by aneuploidy (108, 128).

Chapter 7

GRAINAGE

Grainage (from French *graine,* "seed" collectively) is the establishment of healthy silkworm eggs for production. A systematic approach not only reduces mortality and saves labour but also improves the progenies. The selection and preservation of seed cocoons, the preparation of disease-free layings and their disinfection and incubation are among the important aspects of grainage. The principles governing these operations are basically the same for all silkworm varieties.

The wild nature of the tropical tasar silkworm is reflected in its disuniform and erratic emergence, coupling, egg laying, hatching and other habits. Nevertheless, the techniques evolved during the past decade ensure systematic grainage operations and a stable crop.

7.1 Selection of seed cocoons

After harvesting, the healthy, wellformed and tough cocoons are selected visually for seed, and the dead, deformed and otherwise unsuitable cocoons are discarded. In the absence of an organized seed sector, the selectionof seed cocoons from the market should be based on sample testing. Stocks showing not more than 5–10% infection can be considered for seed.

7.2 Preservation of seed cocoons

The pupal stage of a nondiapausing crop lasts hardly a month, during which the atmospheric temperature and humidity are kept within the optimum range (25–30°C and 70–80% R.H.) for their development; however, when a stock is preserved over the winter, the pupal stage lasts 5–7 months.

Most of the eco-races are bivoltine; only a few are univoltine and trivoltine. In univoltines the diapause extends from August to June, and in bivoltines and trivoltines from November to June and from January to June, respectively. During these periods the pupae experience extremes of temperature and relative humidity (10–46°C and 30–100%), not only causing 25–30% mortality but also adversely affecting the vigour of the ensuing progenies. The optimum temperature and relative humidity for seed cocoon preservation are 25–26°C and 45–50%.

The very simple type of seed preservation house shown in Figures 34 a,b will reduce pupal mortality by as much as 5%. This well-ventilated mud house with walls 60 cm thick, rustic tile roofing, a false ceiling of split bamboo or straw mats and a corridor 2.5 m wide on all sides can maintain a difference of 5–7°C between room and atmospheric temperature. A hut 5x11 m can easily accommodate 100 000 seed cocoons arranged in hanging garlands, and the corridors provide adequate working space for the various grainage operations.

7.3 Transport of seed cocoons

Utmost care is required in transporting seed cocoons to distant places. The cocoons should be packed loosely in split-bamboo baskets (Figure 35) or in perforated plywood boxes. Severe jerking and direct sunlight on the box or basket should be avoided. On consignment the cocoons must be unpacked and hung in the grainage room. Seed cocoons should be transported during diapause, preferably in December and January.

7.4 Emergence

The development of pupa to moth takes about 30 days, during which optimum temperature (28–30°C) and relative humidity (75–85%) are desirable. Indoor conditions normally satisfy these requirements. In the first crop of cocoons the development continues without interruption, whereas in the over-wintering population it begins a month before actual emergence.

Emergence in the diapausing stocks generally coincides with the onset of the monsoon (the last two weeks of June), and in the second and third crops it takes place in August and September and in November and December, respectively. Usually the moths start emerging late in the afternoon, but the peak period is 19:00–21:00 hours (Figure 36).

(a)

(b)

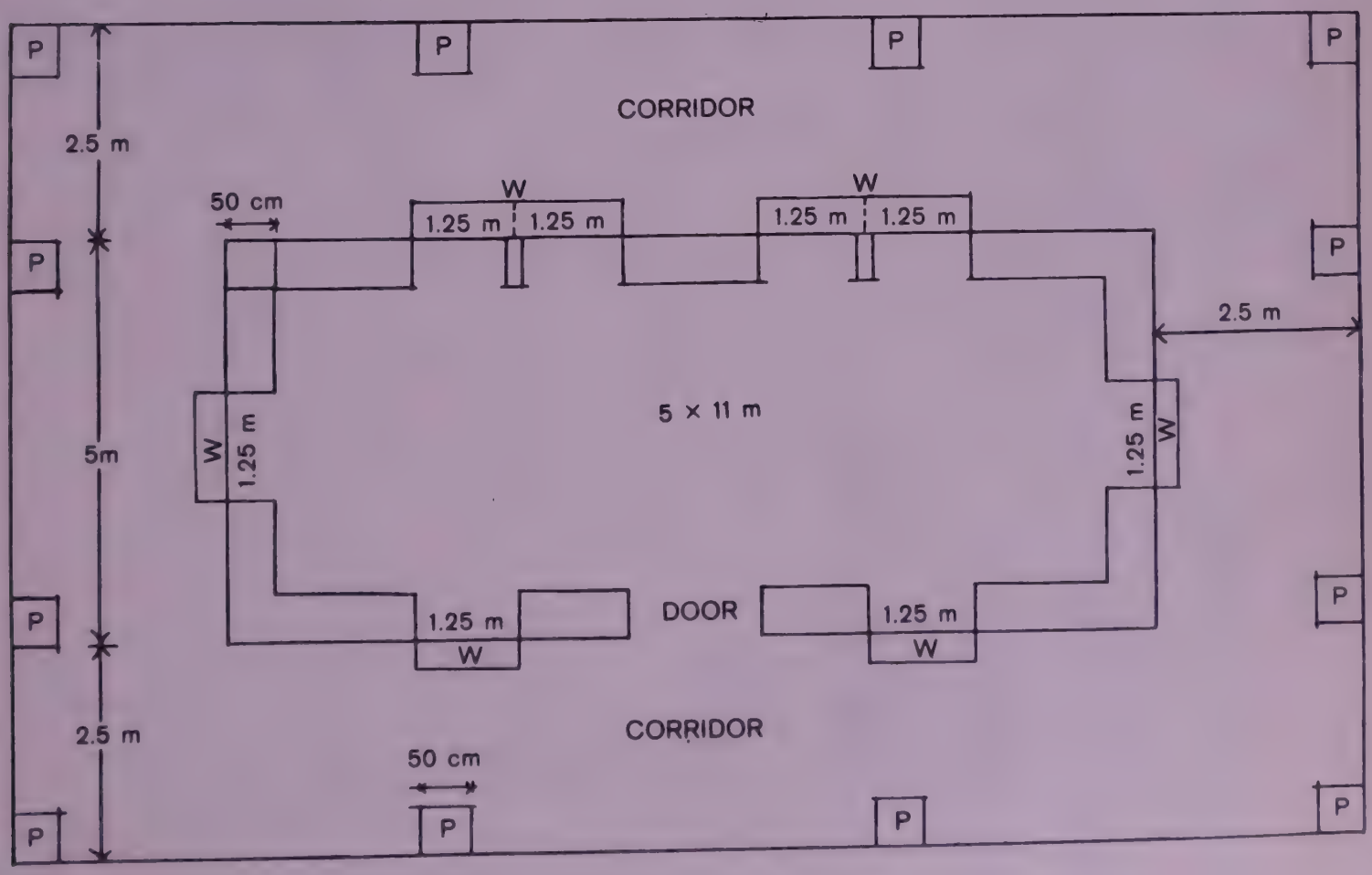


FIGURE 34. (a) Seed preservation house and (b) floor plan

P = brick pillar and W = wooden window fitted with wire mesh

A proteolytic enzyme secreted by the maxillary galeae of the fresh moths facilitates emergence when applied to the peduncle end, rendering it soft and enabling the moth to force its way by making a hole.

Emergence in the natural population takes a month; but with cocoons from the first crop this period can be shortened and the emergence from those harvested on successive days can be synchronized for effective grainage by low-temperature treatment (5°C) of different duration (Table 9).

FIGURE 35. Bamboo basket for the transport of seed cocoons

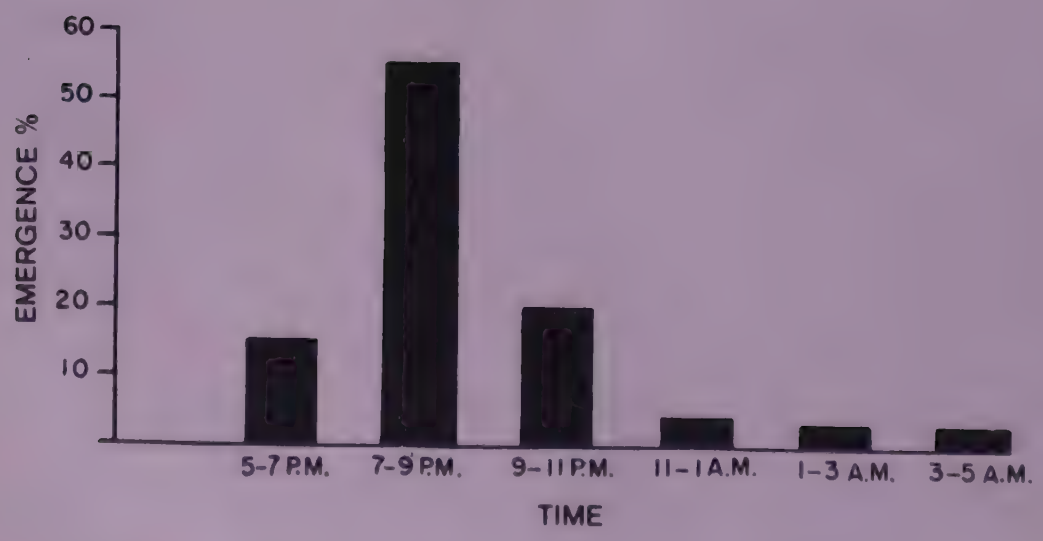


FIGURE 36. Emergence percentages at different hours

Table 9. **Synchronization of moth emergence from first-crop cocoons**

Day of cocoon harvest	Period of refrigeration at 5°C (days)	Emergence (%)	Peak period of emergence after treatment (days)	Span of emergence (days)
1st	6	94	19–21	6
2nd	5	95	18–21	5
3rd	4	97	18–21	5
4th	3	91	18–21	6
5th	2	95	19–21	5
6th	1	89	18–22	6
7th	0	91	19–22	8

7.5 Coupling

After 2–3 hours of emergence the moths start to couple, the peak period being from midnight to 2:00 (Figure 37). Generally, a number of male and female moths are kept in large bamboo baskets for mass

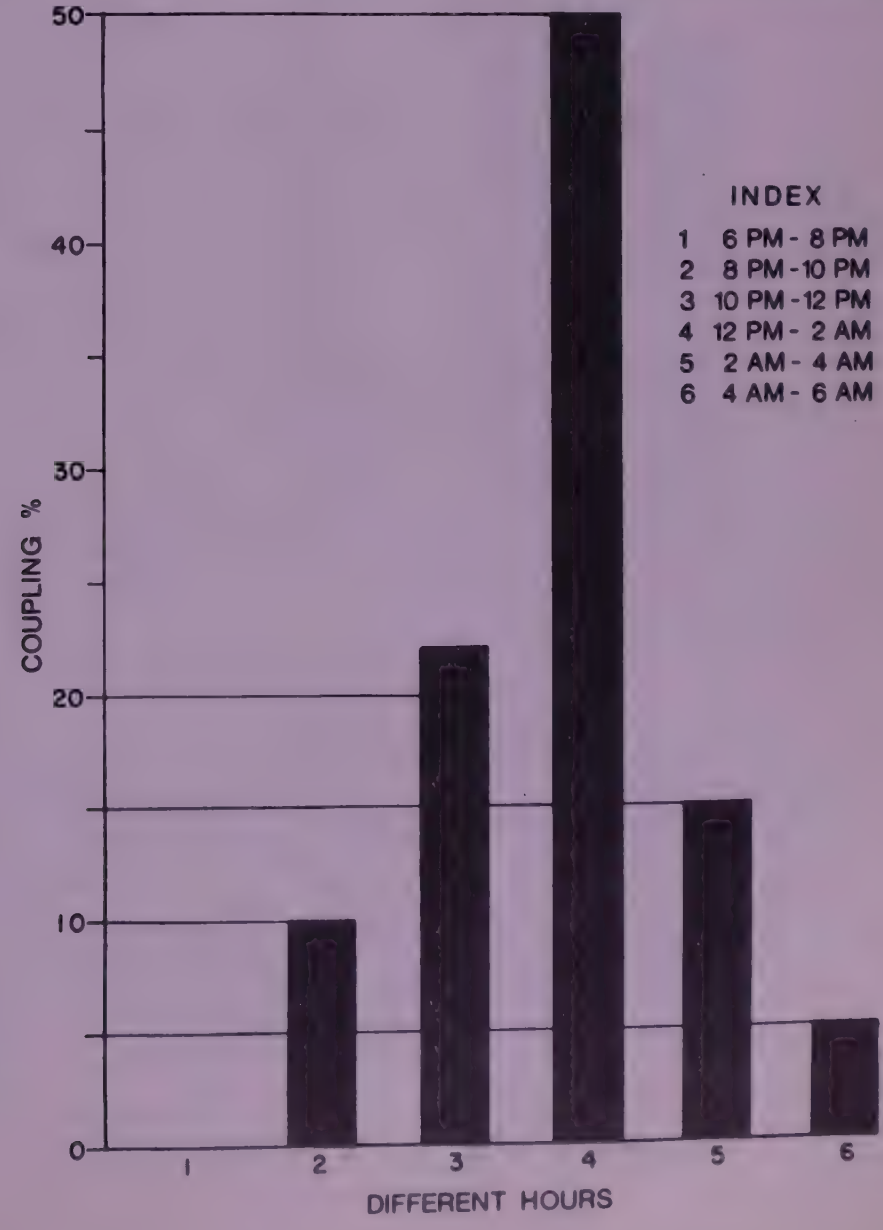


FIGURE 37.
Coupling aptitude at different hours

coupling; however, it is advisable to adjust the moth population to the size of the basket, as the coupling aptitude tends to decrease with density. For experimental purposes, a small bamboo basket known as a "monia" is used for a single pair of moths.

Recent studies show the advantages of outdoor coupling (Chapter 10) for commercial grainage; it is not only about 90% successful as compared to coupling in captivity, but also reduces labour considerably. The virgin females are placed on the bushes in the evening, and then the males are released. The coupled pairs are collected early in the morning to avoid losses due to bird attacks (Figure 38).

A special coupling cage of netted cloth is generally used for interspecific crosses if there is lack of mating aptitude between two species. The males and females of the two species are introduced into two compartments, one of which is meant for cross coupling and the other for reciprocal coupling (Figure 39). The males, on being excited by the sex pheromone emitted by their female counterparts in the other compartment, couple with the females of the other species (92).

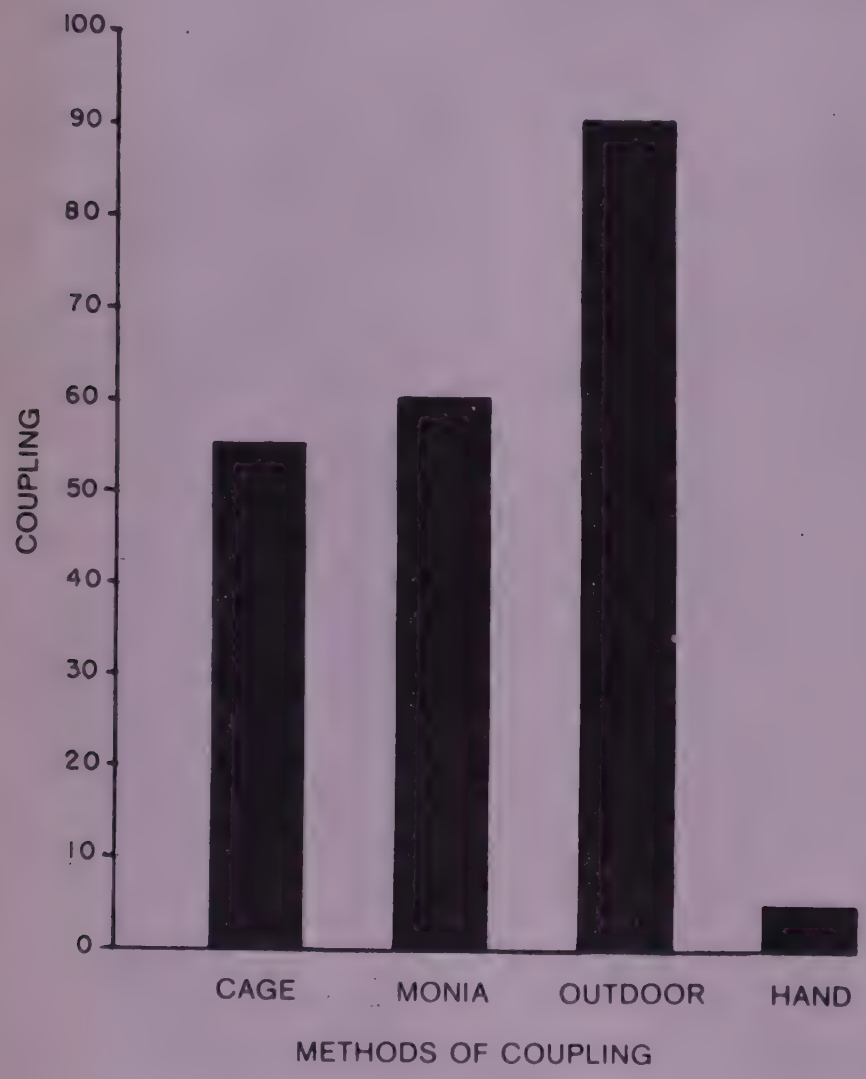


FIGURE 38. Coupling percentages with different methods

Tasar silk moths generally prefer to couple in darkness at a comparatively lower temperature (24–26°C) and high relative humidity (75–85%). A blast of cool air (20–22°C) for 30 minutes to one hour helps raise the coupling percentage during hot, humid weather. Up to 30 minutes of premating flight exercise for male moths also induces a better coupling aptitude.

Although coupling continues for 10–12 hours, a period of 2–4 hours is adequate (3) for ensuring normal fecundity and fertility (Figure 40). The duration of coupling has no direct relationship to the preoviposition period.

In case of a shortage of male moths, they can be refrigerated at 10°C for 2–3 days and then safely utilized a second time.

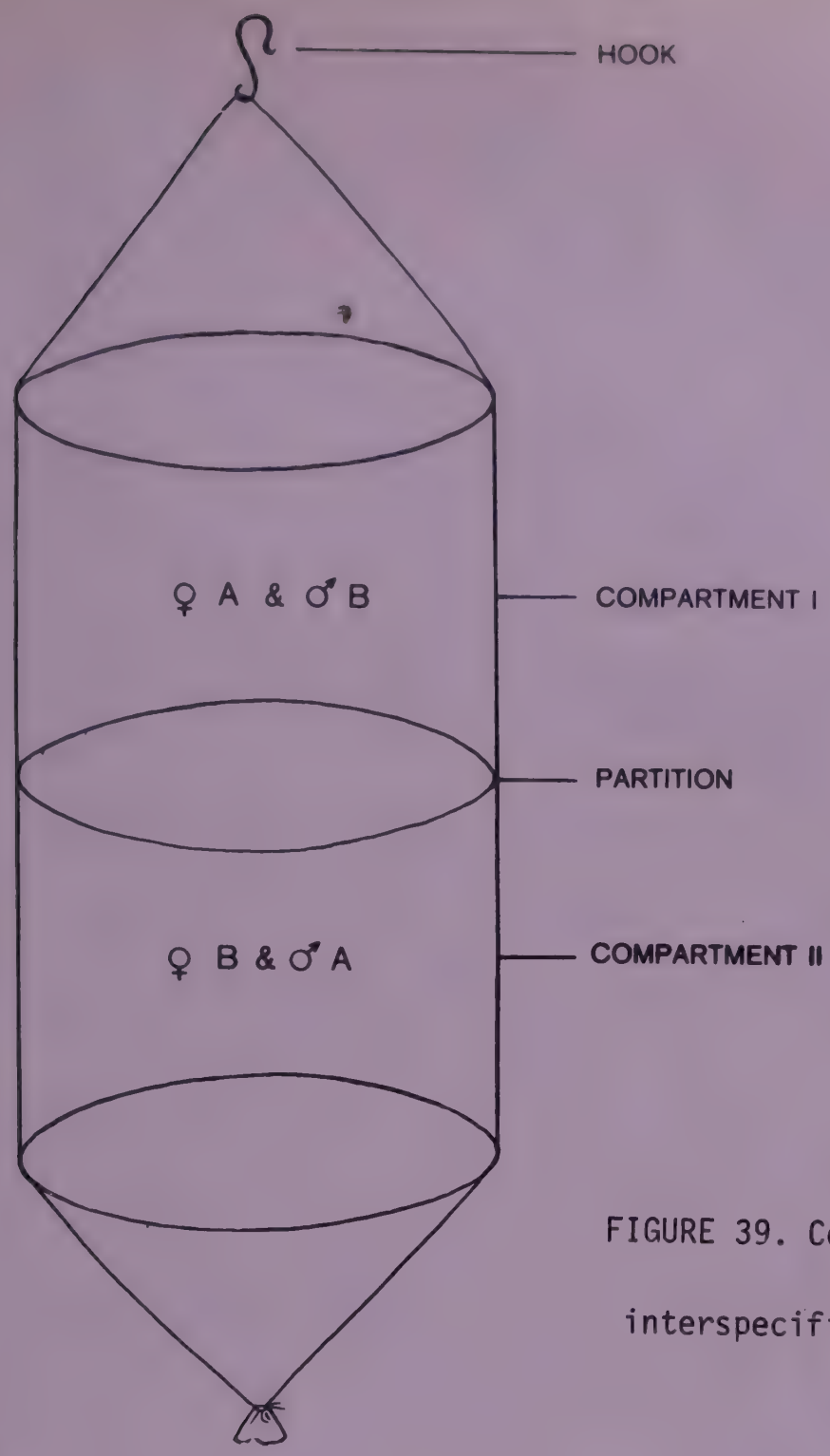


FIGURE 39. Coupling cage for interspecific hybridization

7.6 Egg laying

After the desired period of coupling, the moths are decoupled by hand. The mated females are then placed singly in small cages (monias) or together in large bamboo baskets for egg laying. Moths prefer darkness for egg laying. It has been observed that in complete darkness nearly 50% of the eggs are laid on the first day, whereas with total illumination laying is delayed by one day (Figure 41).

The eggs are deposited in batches of 5–10. The moths from the diapausing crop have a lower ovipositional capacity than those from the nondiapausing crop — the average being 200. The moths normally lay eggs for 6–7 days, but only the eggs deposited within the first 72 hours (85–90%) are considered for rearing.

A mild electric shock (50–100 V) administered to the mother moths showing no tendency to oviposit will induce normal egg laying within 24–48 hours without impairment of the economic characters (Figure 42).

7.7 Selection of disease-free layings

Microscopic examination of the mother moths ensures disease-free layings. A suspension obtained by squeezing the lower abdominal portion of the moth in a little water is examined under a microscope at

10x 40X Special attention is given to microsporidian infection because of its transovarial mode of transmission. The mother moths exhibiting even the slightest hint of microsporidiosis are noted and their layings are rejected. Infected mother moths and their layings should be burned or buried immediately. If other diseases are detected, the layings are rejected only in cases of severe infection (Chapter 10).

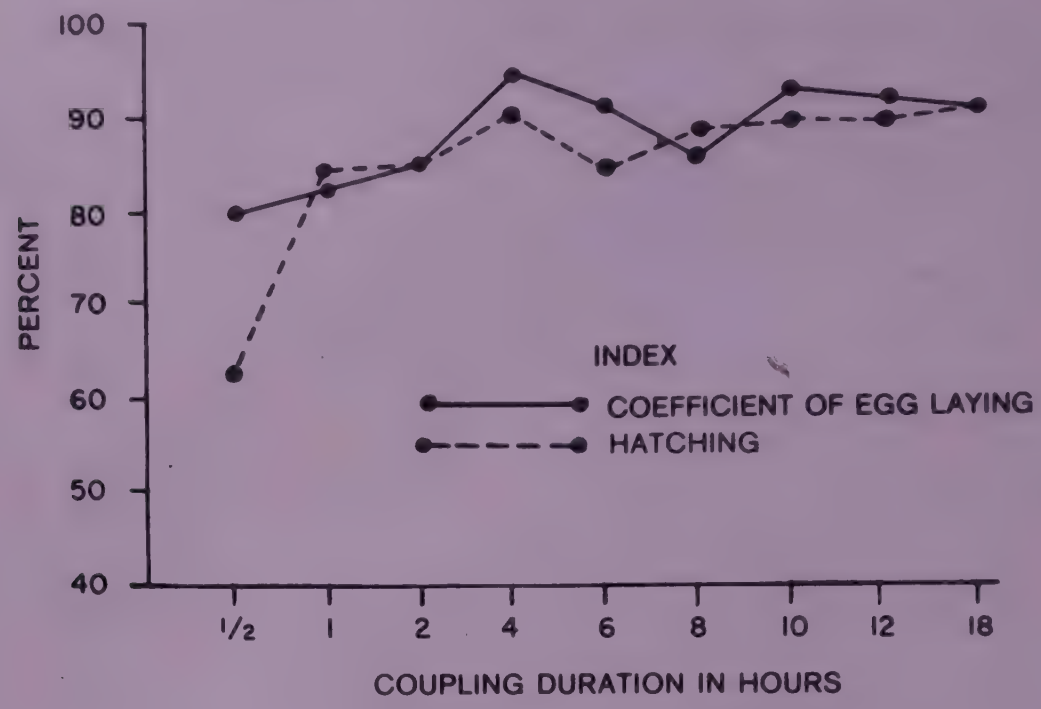


FIGURE 40. Effect of coupling duration on oviposition and hatching

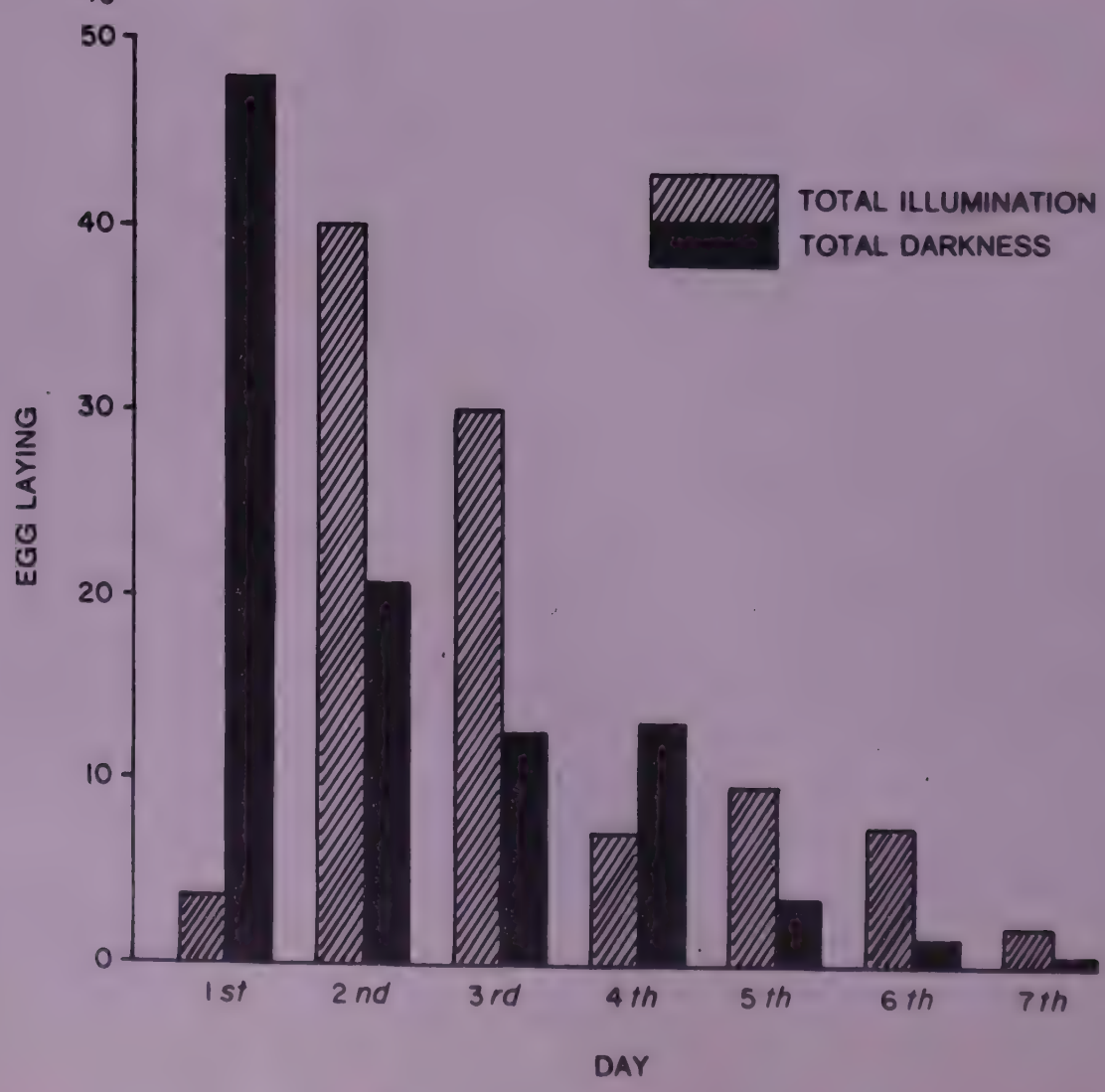


FIGURE 41. Effect of photoperiod on egg laying

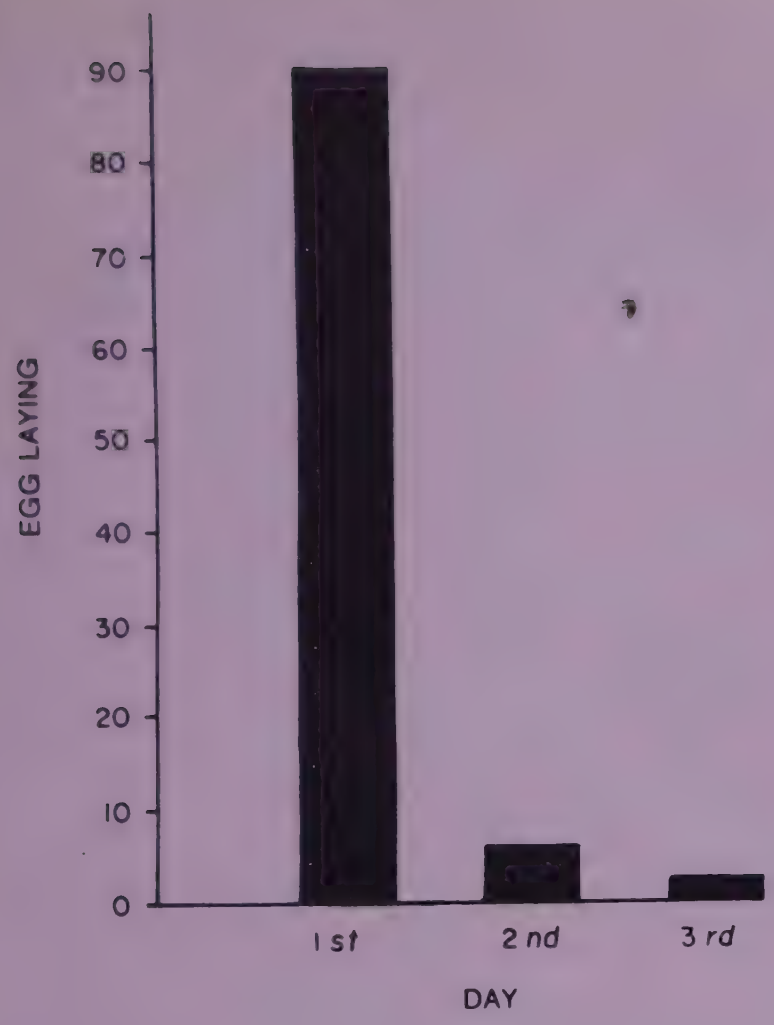


FIGURE 42. Effect of electric shock (100 V) on oviposition

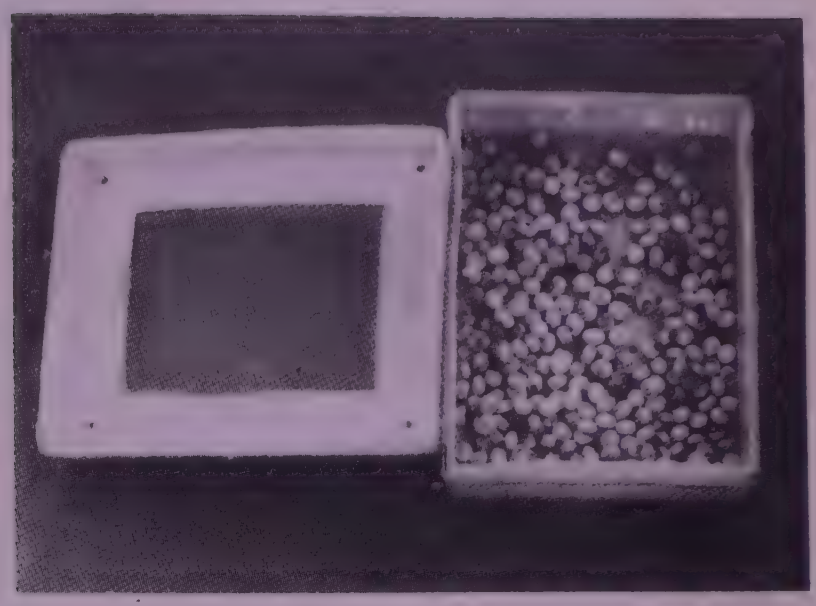


FIGURE 43. Laying box with eggs

Cellular examination of moths is advisable in parental stocks; for commercial grainage a rather large sample should be examined.

7.8 Disinfection of eggs

As tasar silkworms eat a portion of the eggshell during hatching, surface sterilization of eggs should be ensured so as to avoid infection through contamination. The selected layings are placed in clean cloth bags and dipped in water to remove the meconium. They are then rinsed in a 5–10% formalin solution for 5 minutes, followed by a wash in running water. The layings are hung in the incubation room for drying.

7.9 Egg incubation

The disinfected eggs are kept in thin layers in egg boxes made of plastic with a transparent top to admit light and perforated sides and bottom for aeration (Figure 43).

The egg boxes are placed in a room for incubation. Incubation temperatures of 10–25–30°C, 25–30–35°C and 30°C give equally satisfactory results (80–90% hatching), but for operational convenience a steady 30°C is advised. A humidity range of 70–80% is suitable for hatching. Incubation results in uniform and more complete hatching.

7.10 Hatching

The hatching commences early in the morning. The hatching of unincubated eggs begins on the tenth day and continues for six days. The hatching of properly incubated eggs starts on the seventh or eighth day and is completed within two to three days. The percentage of hatching is higher in the eggs laid on earlier days (Figure 44). In tasar silkworm eggs, unlike those of mulberry silkworm, there is no "blue stage", perhaps because of the thick chorion, and hence "black boxing" is not possible.

7.11 Refrigeration of eggs

If necessary, hatching can be delayed a few days by subjecting the eggs to low temperature (8–10°C); however, the duration of treatment should not exceed one week. Refrigeration should begin either at the early stage (within 48 hours of oviposition) or after the completion of embryonic development (120 hours after oviposition). Initiating the refrigeration treatment between these two stages is detrimental to the insect.

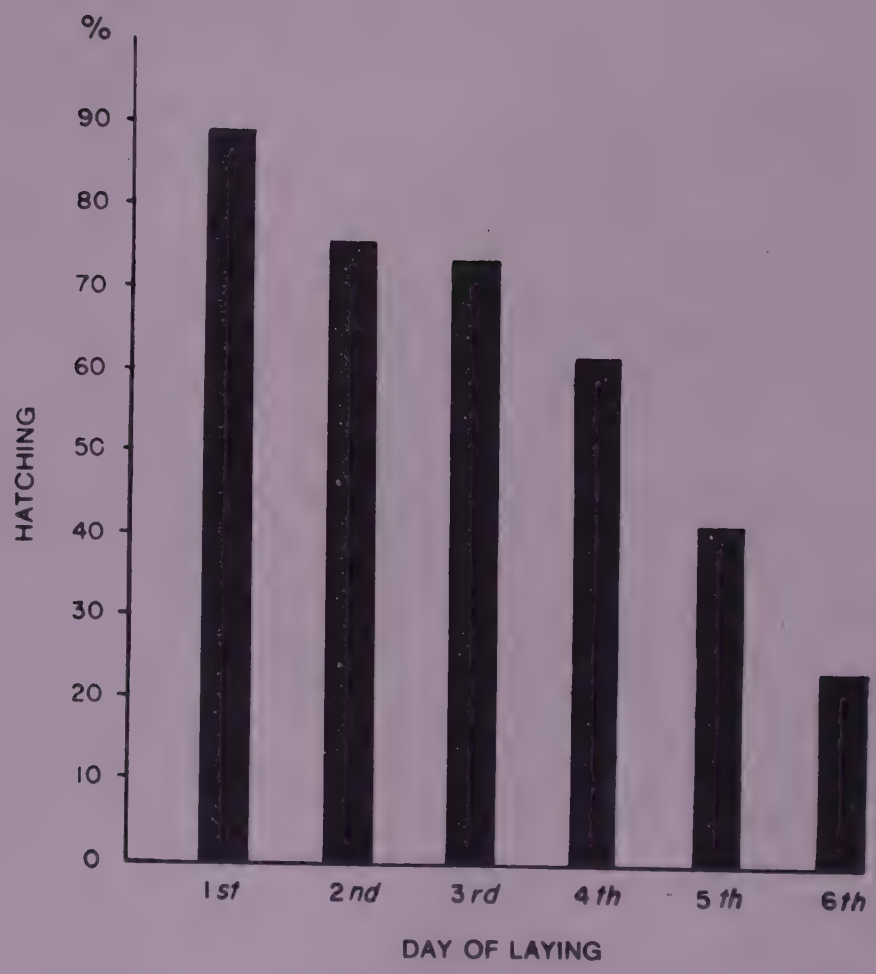


FIGURE 44. Hatching behaviour of eggs laid on successive days

7.12 Termination of diapause

Photoperiodism: Among the different external factors, a long day photoperiod (18 hours) has the most decisive effect on the lengthof diapause in *A. mylitta* (83: Figure 45). Almost identical results can be obtained in less time with equally long photoperiodic treatment at 30°C (80% R.H.). It has been observed that *A. mylitta* has many of the sensitivities to photoperiod of its close relatives *A. pernyi* (200, 201) and *A. polyphemus* (118).

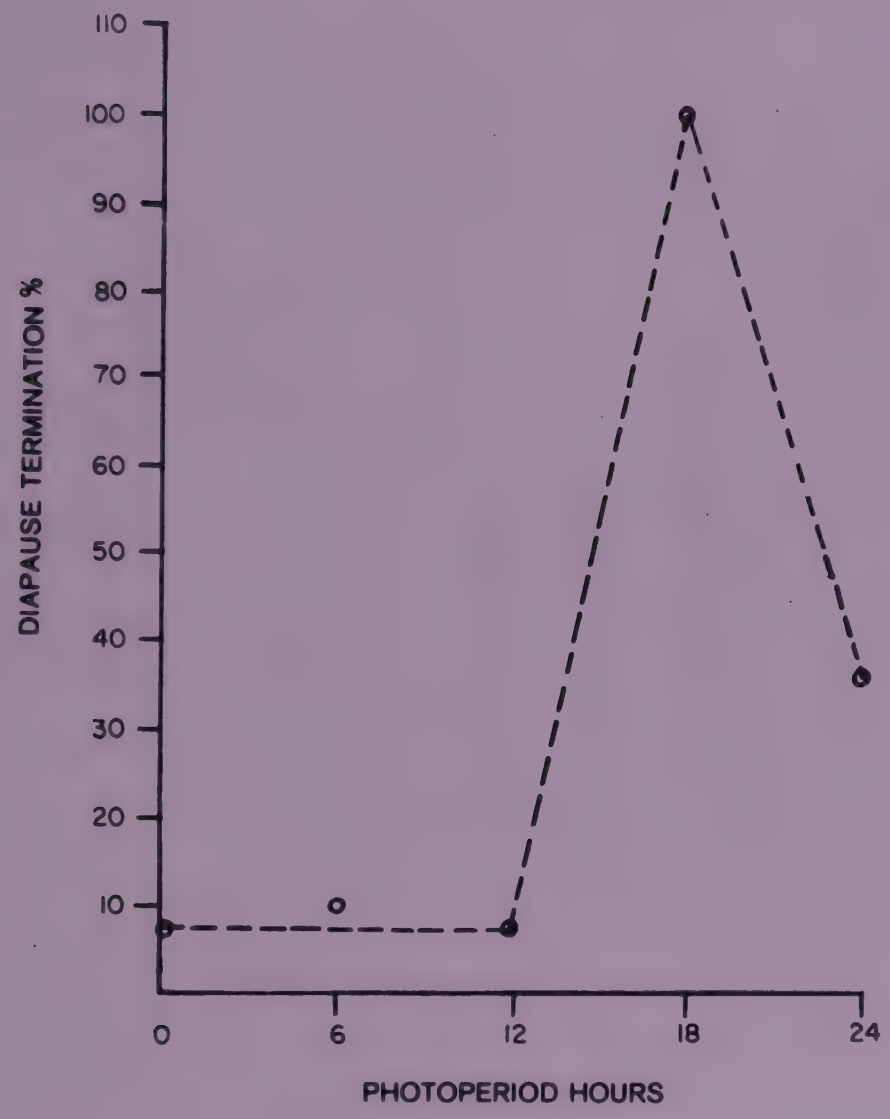


FIGURE 45. Effect of photoperiod on the termination of diapause in *A. mylitta*

Hormonal effect: The recent discovery of plant hormones which act like the insect hormone ecdysone (132) has aroused interest in this field. Injections of the phytoecdysones in diapausing pupae of *Samia cynthia* and *A. pernyi* were highly effective in provoking adult development (202). In *A. mylitta* the most positive response 88–96% emergence in 3–4 weeks and 100% in 8–10 weeks — was observed with a 5–10 microgram dose of cyasterone (4, 89). The other phytohormones — ecdysterone, inokosterone, makisterone and ponasterone A — in a larger dose (30 micrograms) showed 68–91% emergence in 8–12 weeks (Figure 46). Topical application of these phytohormones (cyasterone, 0.005%; others, 0.01%) provoked development within 12–15 weeks; cyasterone once more gave the best results.

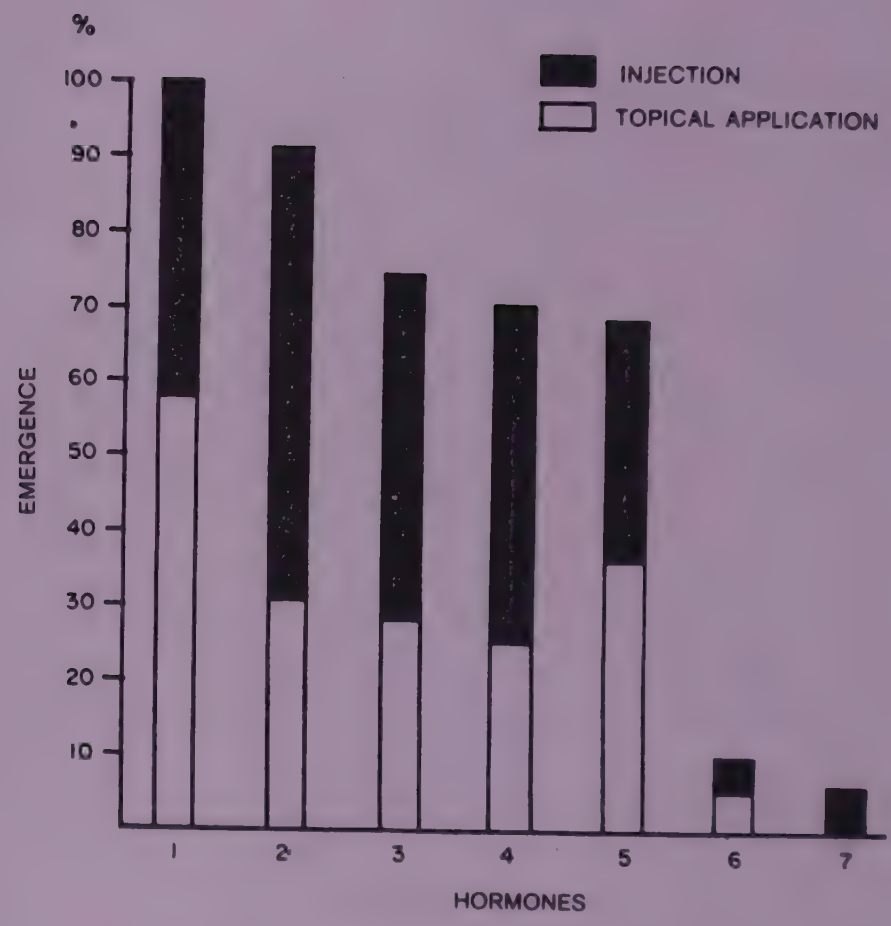


FIGURE 46. Effect of injection and topical application of phytohormones on diapausing pupae of *A. mylitta*:
1) cyasterone, 2) inokosterone, 3) ecdysterone, 4) ponasterone-A, 5) makisterone, 6) control with solvent (methanol) and 7) control without solvent

Chapter 8

ETHOLOGY OF LARVA

A mylitta, being a semidomesticated species, passes the larval period outdoors. This exposure to diverse meteorological conditions — temperature, humidity, sunlight, rain, storm, etc. — affects the vigour and voltinism of the larvae. Nevertheless, they exhibit the characteristic behaviour described below.

8.1 Response to meteorological conditions

Temperature and humidity: The larvae tolerate a very wide range of temeprature and humidity because of their outdoor rearing. They survive at temperatures and relative humidity as high as 34–35°C and 90–100% and as low as 9–10°C and 30–40%. They become restless, however, above 30°C and inactive below 20°C. Furthermore, the relative humidity requirement of early instars is slightly higher (75–85%) than that of late instars (60–70%). The optimum relative humidity for moulting larvae is 40–50%, as higher humidity renders the casting off of old skin difficult.

Temperature and humidity intimately influence the larval span and vigour. Whereas in the first brood (July–August: 24–34°C and 75–85% R.H.) the larval span lasts 30–35 days, in the second (September to October: 20–30°C and 60–80% R.H.) and third (November to January: 18–26°C and 40–60% R.H.) it lasts 40–45 and 60–70 days, respectively. These variations make the larvae susceptible to bacterial and viral diseases (167). Mortality from bacterial diseases is aggravated by low temperature (20–25°C) combined with low humidity (55–60%), and from viral diseases by the cumulative effect of high temperature (30–32°C) and high humidity (90–95%).

Sunlight: Newly hatched and early–instar larvae avoid bright sunlight and therefore usually rest on the underside of the leaves. Late–instar larvae prefer bright sunlight but move to shade when the sun is very strong. During moulting and cocoon formation they prefer shade. The long– and short–day photo–periodic conditions, particularly during the last two instars, considerably influence the voltinism of the insect.

Rain and storm: In breeze and drizzle the larvae continue to feed normally. Gusty wind, heavy rains and storm are disturbing, especially to first–instar larvae, which are easily washed or blown away.

8.2 Larval behaviour

Feeding: The larvae feed from the margin to the centre of leaves, but they never eat the midrib. The younger larvae rest on the leaf margin, and the older ones attach themselves to petioles or even small twigs with the help of their abdominal feet and claspers. The leaf lamina is pulled up between the mandibles by the thoracic legs.

The early instars relish tender leaves, and the advanced stages prefer medium to mature leaves. On average, a larva consumes nearly 300 g of foliage (92), about 20% during the first four instars and 80% during the fifth instar (Table 10).

The rate of feeding is minimal before and after the moult, but reaches its peak between these two periods. Every stretch of feeding is followed by a rest period of about five minutes or of longer duration in winter and unfavourable weather. While resting, the larva raises its head, contracts its body and assumes a typical sitting posture (Figure 47). Feeding, with rest periods, continues round the clock, except when the mercury drops below 15°C.

Moult: The larvae stop feeding just before the onset of a moult and become motionless. They secure a firm grip on either the underside of leaves (early stages) or the shaded part of twigs (late stages). During the moult the anterior part of the body remains obliquely suspended, the prothoracic hood is fully stretched and the protruding dark head is bent ventrally inward (Figure 48). They seldom lose their grip, but once detached they cannot reestablish and moult with difficulty.

During ecdysis the old head capsule is detached intact along the vertex, after which the larvae push forward, splitting the old skin along the mid–dorsal line. Moulting continues for 23–24 hours

depending on the climatic conditions. The freshly moulted larvae have tender, pale skin. They eat a portion of the cast-off skin and commence active feeding after a brief rest.

Table 10. Average leaf consumption of an *A. mylitta* larva during July and August

Instar	Leaf consumption (g)	Total feeding time* (h. min)	Rate of feeding (%)
I	0.88	97.45	0.29
II	1.29	87.00	0.44
III	15.78	120.45	5.27
IV	37.93	204.00	12.66
V	243.70	336.00	81.34
Total	299.58	845.30	100.00

*Excluding moulting and cocooning.

FIGURE 47. *A. mylitta* larva at rest

FIGURE 48. A fourth-instar larva under moult

Larval growth rate: Tropical tasar silkworms have a remarkable growth rate (136). Their length, width and weight increase from about 7 mm, 1 mm and 8 mg, respectively, at hatching to about 13 cm, 2.1 cm and 50 g at maturity (Table 11).

Cocooning: The larval feeding phase ends at maturity, marked by evacuation of the gut contents or "passing of last excreta", as a green semisolid mass followed by a colourless slimy substance. Exploration for a cocooning spot starts after 10–25 minutes of rest and may last for 1–1.5 hours. A group of three or more leaves is usually chosen. The formation of the cocoon, which can start at any hour, is completed in the following stages (25).

Hammock formation: The larva joins the leaves to form a small nest or hammock, with an opening at the top by irregularly throwing out silk filament (Figure 49). It spends nearly 6 hours completing the hammock.

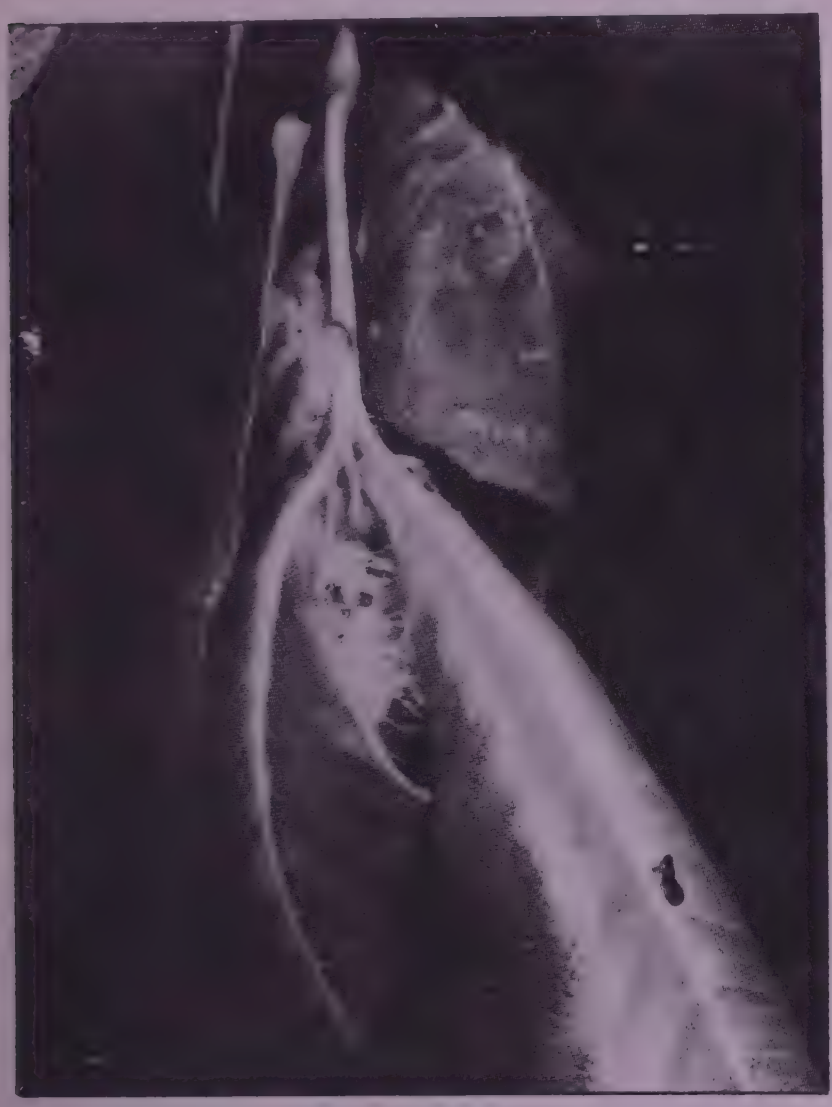


FIGURE 49. Leaves in hammock formation

Table 11. Growth and growth rates of *A. mylitta* larvae

Growth pattern	Hat-ching	Instar II	III	IV	V	Maturity	Absolute growth rate
Length (mm)	7	20	40	65	100	130	x 20
Growth rate	–	2.9	2.0	1.4	1.3	1.3	
Width (mm)	1	4	7	10	18	21	
Growth rate	–	4	1.8	1.4	1.8	1.2	x 21
Ponderal (mg)	8	670	4 950	7 090	13 000	50 000	
Growth rate	–	83.7	7.4	1.4	1.8	3.8	x 6 250

Ring and peduncle: The larva moves out of the hammock and withits mandibles straps bark 2–3 mm wide around the twig in the form of a ring in 25–30 minutes; the space within the ring is then filled with silk (Figure 50). Simultaneously, the peduncle foundation is laid by connecting the ring to the top of the hammock with a few strands of silk; it is later completed by adding more strands (Figure 50).

The usual to–and–fro motion of the head during these operations changes to semicircular and linear during ring and peduncle formation, respectively. These stages are completed in 10 hours.

(a) (b)

FIGURE 50. Formation of (a) ring and (b) peduncle

Cocoon: After formation of the ring and the peduncle, spinning of the cocoon is initiated, usually during the daylight hours. During spinning, which is most regular, the head movements of the larva trace a horizontal figure eight. In 24 hours the larva is completely enveloped by the cocoon; but spinning continues for another 2 to 3 days, during which the cocoon shell is further thickened (Figure 51). The larva should not be disturbed during spinning. After spinning it places it head towards the peduncle end.

Before pupation, which takes 4 to 6 days, the larva very slowly discharges a small quantity of light milky yellowish substance for 2 to 3 hours. Upon drying, the discharge makes the cocoon yellow or grey.

FIGURE 51. Cocoon formation in progress

Chapter 9

REARING

Outdoor rearing exposes tropical tasar silkworms to unfavourable weather conditions and attack by pests and predators. These account for losses of 50–55%, mainly during the early instars. Besides, the improper handling of larvae and the faulty selection of rearing site and plantation, for example, cause severe harm to the health and vigour of the population, which is reflected in a higher–rate of mortality from disease (35–40%). Losses can be substantially decreased by a more rational approach to rearing.

9.1 Rearing operations

The fate of the crop largely depends on choice of rearing site and food plants, brushing, supervision and maintenance of larval population and other rearing operations. Slackness in any of the operations adversely affects the yield. The following discussion of rearing operations points out the merits and demerits of various improved and traditional methods.

Selection of rearing site and food plants: The traditional tasar rearers usually utilize the sparsely distributed food plants on the bunds of paddy fields. Waterlogging in the fields during rains raises the relative humidity. Also, excreta and dead larvae which have fallen into the water putrify and pollute the environment. During the dry winter months the scattered plants fail to maintain the atmospheric humidity at the desired level. All these conditions promote the outbreak of diseases.

It is desirable to avoid low–lying areas. Fairly thick patches of food plants of 3.0–3.5 m tall are ideal. The bushes must not be utilized for two successive crops in a year.

Rearing preparations: Before the onset of rearing, the site and the surrounding area should be cleared of weeds, which might otherwise induce pest and predator attacks. Apart from removing the unsuitable foliage, care should be taken to free the bushes of insects, particularly ants nests. A band of straw with a little ash should be tied around the trunk to check the downward movement of larvae. The trunk base should be encircled with a thin band of gammexane to prevent attack by ants and other insects.

Quality of leaf: Quality of foliage in relation to larval age is a major determinant of health and vigour. The younger larvae thrive on juicy, tender leaves, while reddish or pale green foliage is harmful. The latter instars require medium to mature leaves. Outdoor rearing cannot ensure provision of the proper quality of leaves during the different instars. Nevertheless, this can be achieved to a degree through various cultural operations and selective utilization of food plants.

Brushing: Brushing is the placing of the hatching larvae on the leaves. The traditional cultivators tie the leaf cups containing the eggs on the bushes for hatching. Both the developing embryo and the newly hatched larvae are thereby exposed to fluctuating temperature and humidity heavy rain, storms and other hazards. This results in poor hatchability and heavy losses of larvae.

A small twig should be placed over each of the newly hatched larvae, which are then tied on the bushes in a uniform distribution. This operation should not be carried out in strong sunglight, heavy rain or other incelement conditions.

Supervision and maintenance of larval population: Outdoor rearing calls for dawn–to–dusk vigilance against pests and predators. Traditional cultivators brush the larval population too densely without regard to the quantity of foliage. This high density decreases effective yield owing to the higher disease mortality and also adversely affects the economic character of the cocoon (178).

Frequent direct handling of the larvae causes considerable injury to their health and contaminates the population. It is therefore desirable to transfer the larvae only once or twice bycutting off the small

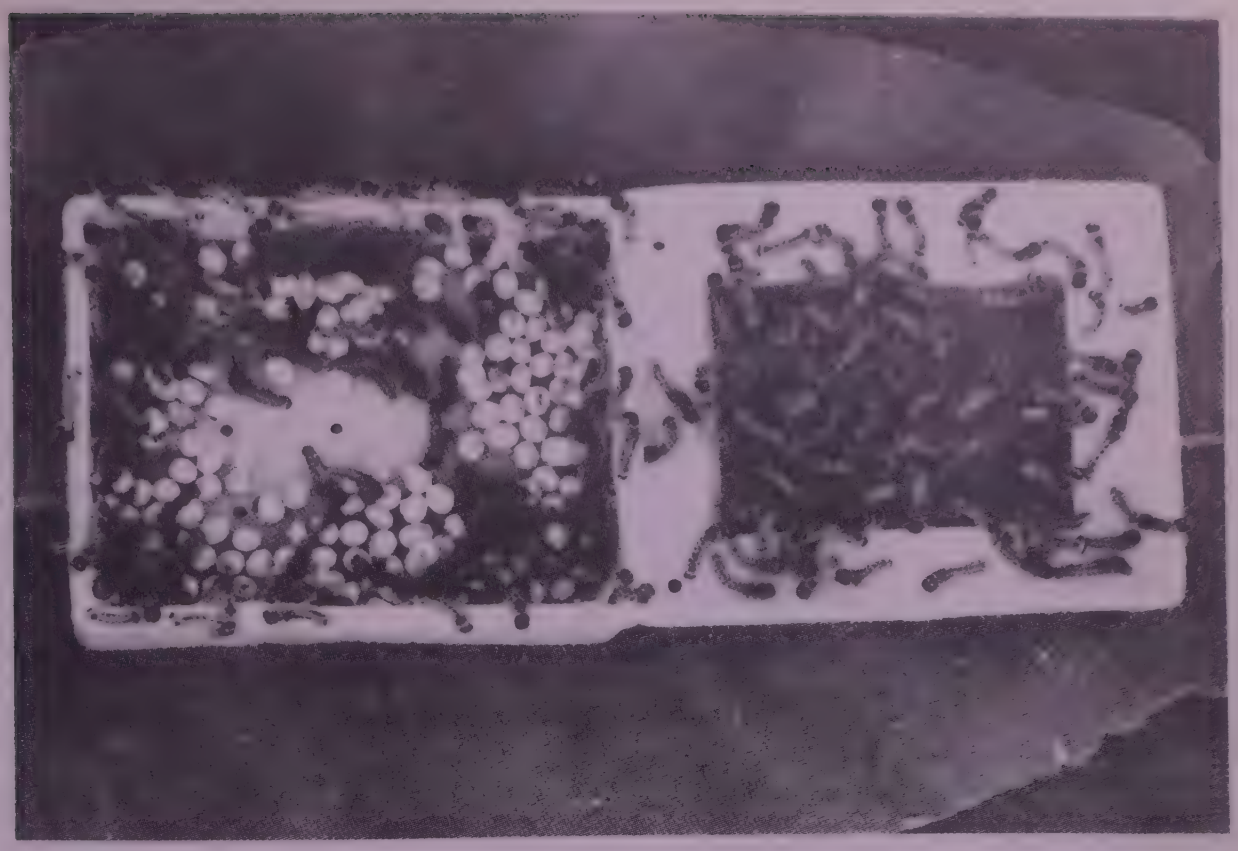


FIGURE 52

Egg box with hatched larvae

branches bearing larvae and attaching them to unused food plants. A secondary advantage of this system is light pruning of the plants.

Moulting and spinning larvae also need special attention; the former should not be disturbed, and the latter require enough foliage to form the hammock properly.

Dead larvae hanging on the bush or fallen to the ground should be collected every morning and evening. A sample of the dead larvae should be examined for microsporidiosis. All the dead worms should be buried outside the rearing site.

Larvae showing symptoms of microsporidiosis as well as the foliage should be destroyed. Those manifesting other diseases should be reared separately. The rearing appliances and the hands of field workers should be disinfected with Dettol water after every contact.

The cocoons should be harvested after six or seven days. The branches are cut and the cocoons are pulled off the twig by breaking it near the ring. The adhering leaves are removed, and the cocoons are graded.

9.2 Improved rearing techniques

There is a very heavy population loss, particularly during the first instar, due to outdoor rearing. Attempts at total indoor rearing have so far not been successful; however, controlled rearing techniques have been developed to protect the early stages.

Controlled rearing: Until the first moult the larvae are reared indoors (80, 84). The essential equipment and the rearing technique are described in the following paragraphs.

Rearing set: It consists of a waterfilled bottle holding 3 to 5 twigs (about 60 cm long) with quality foliage and a cylindrical polythene enclosure with a split-bamboo frame (Figure 53). The cut end of the twigs is inserted well under water. This arrangement keeps the foliage turgid for 3 to 4 days feeding. Proper clustering of the foliage to form a nest at the centre of the set prevents the larvae from crawling onto the polythene. The mouth of the bottle is plugged, not to protect the larvae from drowning, but also to check an increase in humidity due to gradual evaporation of the water. The rearing capacity

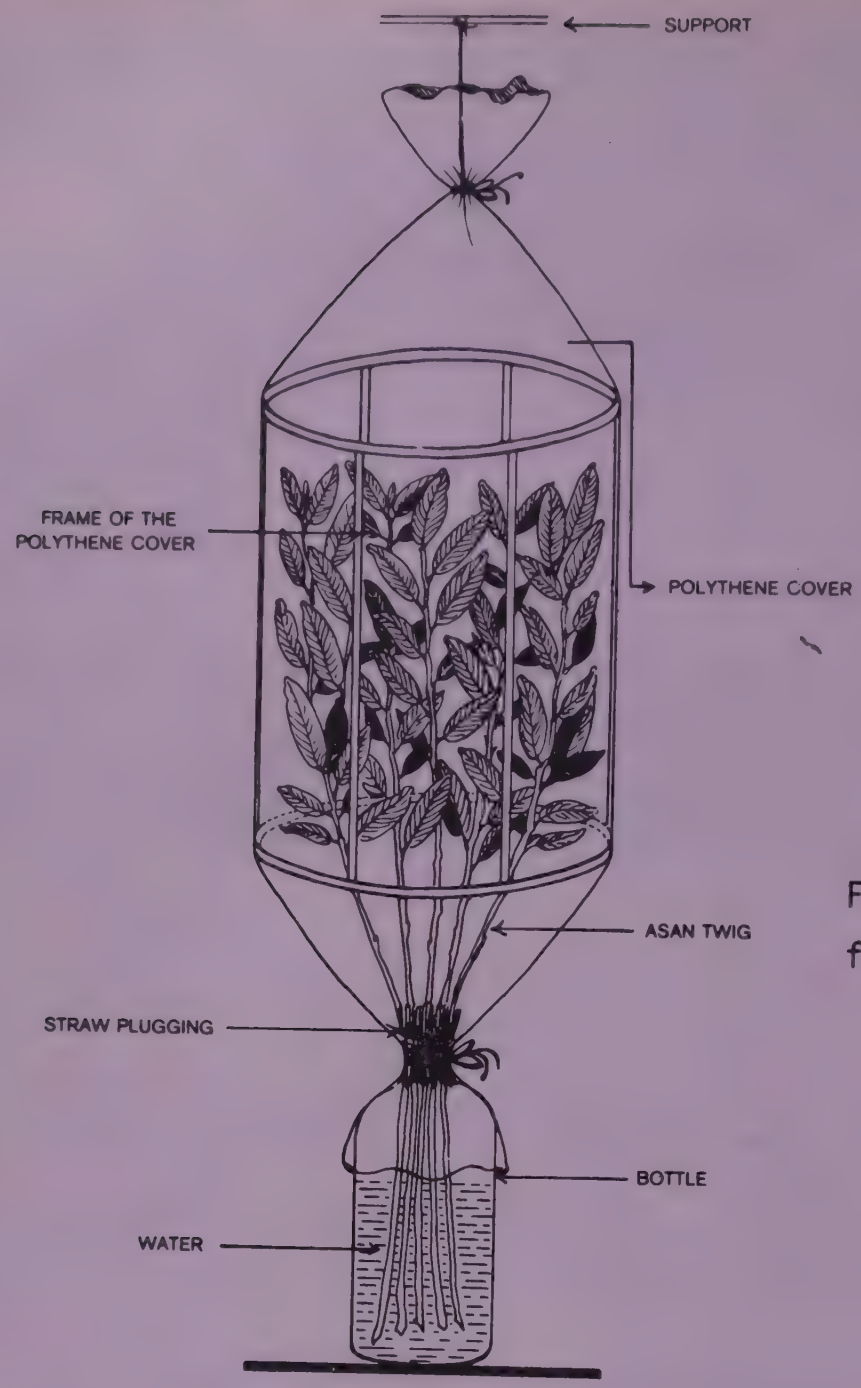


FIGURE 53. Controlled rearing set for early-instar larvae

of the set can be increased considerably by using a big earthern pot or tin container.

Brushing is conducted according to the improved technique of using only one day's hatchings and avoiding overcrowding. The polythene enclosure, which is tied at the bottom around the neck of the bottle and fastened at the top to a support, should be opened for about 15 minutes daily for cleaning and for adequate aeration. Special care should be taken to remove the enclosure as soon as the larvae start settling to moult; otherwise the ecdysis is so difficult as to cause heavy mortality. The larvae coming out of moult are allowed to crawl onto fresh twigs and transferred outdoors, observing the precautions previously discussed.

Rearing huts: The rearing sets are placed inside a hut thatched with straw or leafy branches (Figure 54). It should be constructed on ground that is high enough to be free from waterlogging. The floor should be raised 15 cm above the ground to avert flooding by rain water. The hut should be bordered with a thin band of gammexane to keep away ants. The open side should not directly face the sun and should be closed at night and during bad weather.

A hut 6 x 3 m can accommodate about ninety rearing sets arranged in three parallel rows in two tiers. The space between the rows provides working room and the spacing of the rearing sets facilitates handling.

Benefits of control rearing: Under the traditional rearing method the loss in the first instar alone is generally 30%. During the remaining larval instars the losses from diseases and pests are 45 to 50% and

from natural calamities 10%. Controlled rearing reduces not only the first instar losses to as low as 5% but also disease mortality during the subsequent stages. The effective yield thereby increases to 50 to 60 cocoons per disease-free laying (df) against 15 to 20 with the traditional method. In India an average family of tropical tasar rearers manage 300 to 400 disease-free layings.

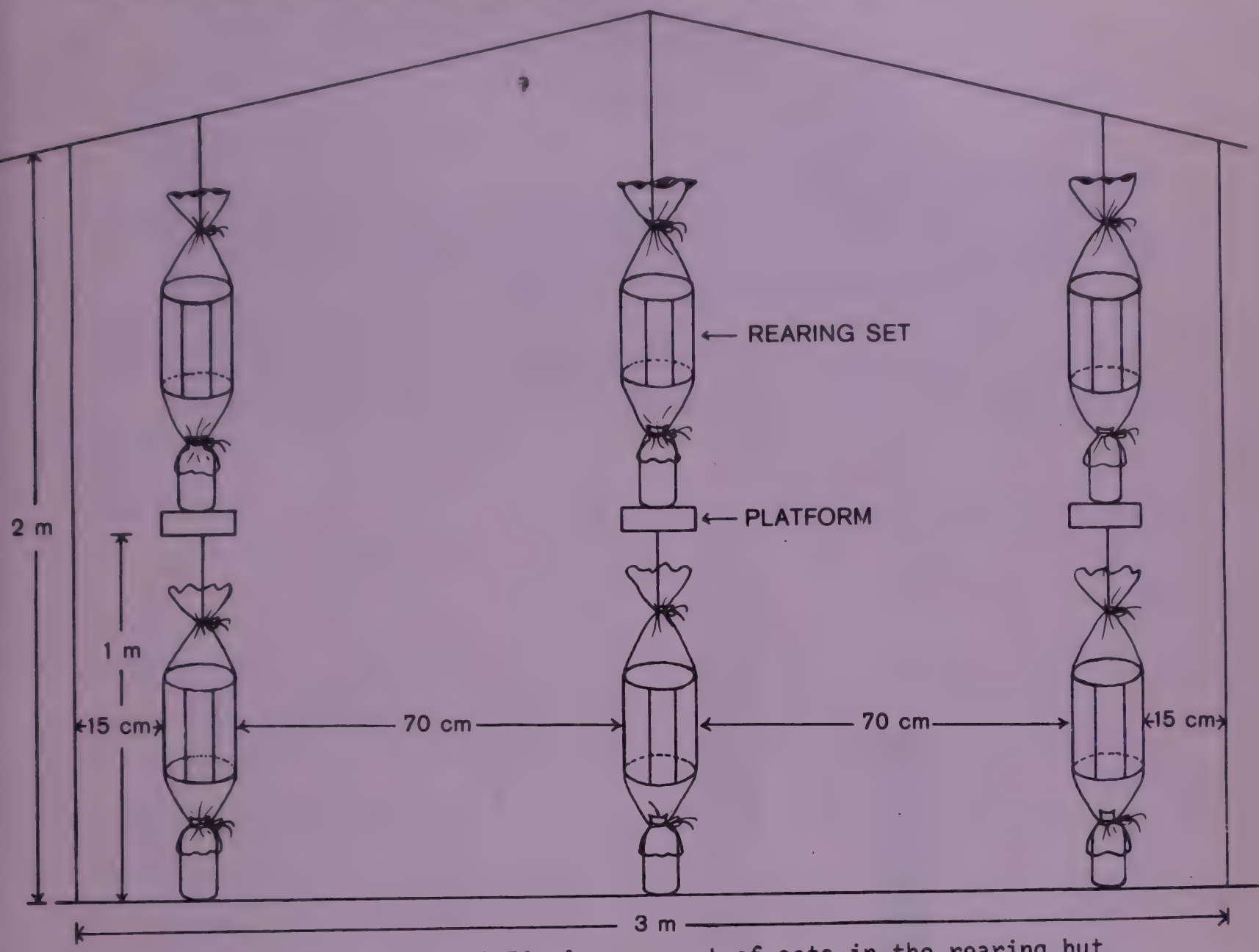


FIGURE 54. Arrangement of sets in the rearing hut

Early-instar rearing centres: The development of economic plantation of tropical tasar food plants has promoted the cocept of early-instar rearing centres. The technique is a further improvement on the basic principle of controlled rearing.

Rearing up to the third instar is conducted on economic plantation, preferably under nylon netting. Although the overlapping twigs allow the larvae to crawl from one bush to the other, the medium size and regularity of the plantation not only permits more efficient management, supervision and operation but also minimizes losses (Figure 55). Moreover, the larvae are more vigorous as a result of being reared under natural conditions with almost no intervention.

As soon as the larvae have passed the second or third moult, the twigs bearing them are cut and transferred to forest or block plantation for rearing in the advanced stages. To save time and labour in the transfer of early-instar population, the rearing centres should be situated as close to the forest as possible.

About 4 000 disease-free layings (dfl) can be reared up to the third instar on one hectar of economic plantation. The loss during the early instars is reduced to 5 to 6% against 40 to 50% during the corresponding period with the traditional method. Also the advanced stages are less susceptible to diseases. The technique therefore yields a stable and rich harvest of 80 to 100 cocoons/ dfl (Figure 56).

FIGURE 55. Early instar rearing under nylon netting on an economic plantation

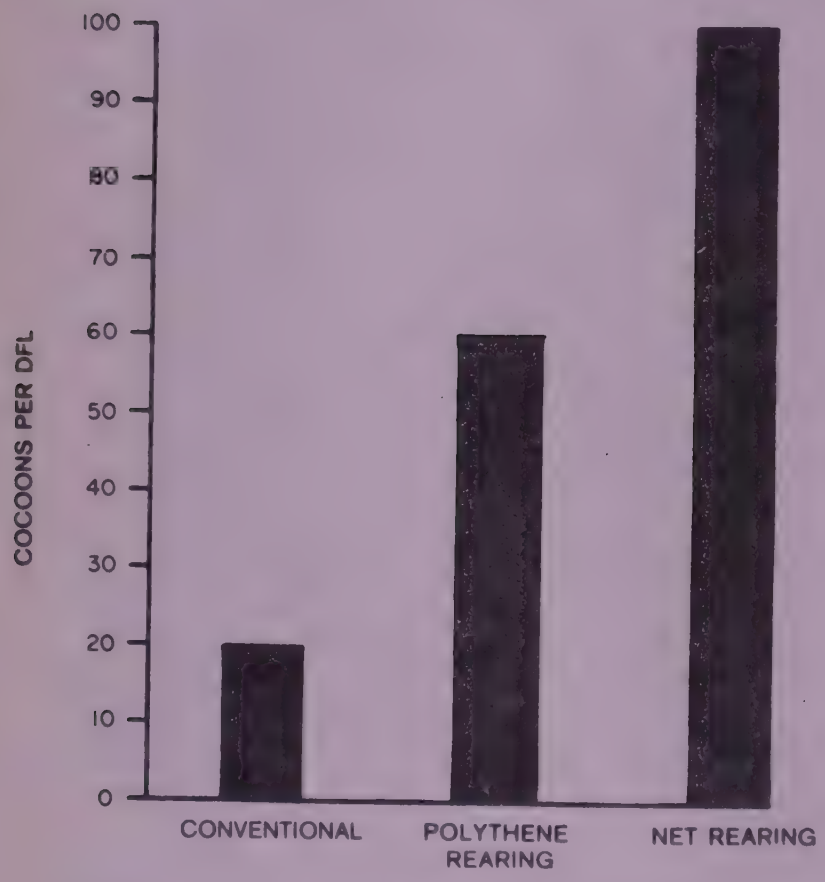


FIGURE 56. Cocoon production per disease-free laying under different rearing methods

Furthermore, labour at the cultivator level is reduced substantially by approximately fifteen days of rearing at the centre and the consequent handling of more or less uniform populations. The centres can be organized as cooperatives of ten member rearers each. Table12 shows expenditure and returns for one hectare of economic plantation with a rearing capacity of 4 000 dfls and an expected yield of 80 cocoons/dfl, or a total of 320 000 cocoons (250 kahans).

9.3 Seed production and supply

For seed the tribal cultivators depend largely either on wild cocoons or on the local cocoon market. Of the current annual requirement of over 5.5 million disease-free layings, the various government agencies are able to supply barely one million and, at that, unsystematically. Whereas in Bihar seed is distributed in the form of dfls, in the other states mostly seed cocoons are supplied. In fact, the unavailability of quality seed is the major obstacle to expansion of the non-mulberry silk industry.

Table 12. Economics of a cooperative early-instar rearing centre on economic plantation

Expenditure		
Maintenance of one hectar of economic plantation	Rs. 2 000	
Cost of seed cocoons	2 400	Rs 200/kahan
Labour charges for grainage and early-insar rearing	1 000	For 10 labourers for 20 days at Rs 5 each per day
Labour charges toward advanced-stage rearing	10 500	For 60 labourers for 35 days at Rs 5 each per day
Depreciation of nylon netting	500	
Miscellaneous	600	
Total (A)	Rs 17 000	
Income		
Sale of 250 kahans of cocoons	50 000	
Sale of 12 kahans of pierced cocoons for seed	1 000	
Total (B)	Rs 51 000	
Net income of cooperative (B–A)	34 000	Cooperative of ten rearer members
Net income per member rearer	3 400	

A seed sector soundly organized on sicentific lines is urgently needed for the renewal of this neglected sector (98). Considering the abundant availability of the essential components of tasar culture, the demand for seed is bound to multiply once a supply system is set up.

Organizational prerequisites: Early-instar silkworms, rather than seed cocoons or dfls should be used for seed, spite problems encountered during grainage operations and rearing. Therefore, the organization of seed production and supply entails the following prerequisites for effective operation.

Seed unit: Each seed unit should be adequately equipped for grainage operations of about 100 000 layings with a mud grainage hut, two ordinary microscopes, disinfectants and other essentials. For the early-instar rearing of 4 000 dfls one hectare of economic plantation should be raised, and the block plantation for their advanced-stage rearing should be about 50 ha.

Seed zone: Apart from ensuring the supply of early-instar silkworms, the seed zones must be absolutely free of all infections which are ascertainable through regular microscopic examination. The rearing site should also be as far as possible from the commercial belts and have a high concentration of foliage-rich plants.

Legislation: The objectives of seed organization cannot be attained unless unauthorized production and marketing are prohibited through legislation. If need be, the government can request the services of certain progressive rearers for the technically controlled preparation and supply of disease-free layings or early-instar silkworms.

System of operation: The seed organization should be comprised of a seed maintenance farm and a seed multiplication and supply farm. The former maintains the basic seed stock, and the latter reproduces the stock and supplies the rearers with early-instar silkworms.

Seed maintenance farm: Each unit should be charged with (a) the collection, evaluation and maintenance of superior races and hybrid stocks and (b) the acclimatization of commercially promising eco-races. From a crop of 200 kahans, 190 kahans should be distributed to the multiplication and supply farms (10 kahans per unit), and the remaining 10 kahans are retained for stock maintenance.

Seed multiplication and supply farm: Multiplication for seed stock and for commercial supply should be carried out in two phases in the first, 10 kahans reproduce at least 200 kahans of seed stock. In the second the seed stock of 200 kahans reproduce about 64 000 dfls, which should be distributed to twenty early-instar rearing centres (3 200 dfls each). In turn each of these centres should supply an equal number of third-instar larvae to ten rearers for commercial rearing.

Chapter 10

PATHOLOGY

Nearly 35 to 40% of the tasar crop is lost from disease (65). The tasar silkworm is subject mainly to four types of diseases: polyhedrosis (virosis) bacteriosis, mycosis and microsporidiosis.

10.1 Polyhedrosis (virosis)

Symptoms: The infected larva becomes soft and sluggish. In about 18 hours the body loses its natural shape, becoming distended and swollen (169). The integument turns opaque and brownish, and the internal tissues disintegrate. The larva dies about 24 hours after the appearance of the symptoms.

After death it hangs head down, remaining attached to the plant twig only by its claspers (Figure 57), and a dark brown fluid oozes in drops from the mouth. The skin becomes fragile and blackish. The dead larva emits an obnoxious odour and becomes a mass of melted tissues.

Infected individuals may succumb during spinning, after pupation or even at emergence. The dead pupae "melt", generally dirtying the cocoon. The life span of infected adults is shortened and their fecundity reduced.

Causative agent: This virus disease is characterized by the presence of polyhedral inclusion bodies, which are cytoplasmic (CPV). They are highly refractile crystalline bodies occurring singly or in groups and ranging from 3 to 8 microns in size. The crystals are usually hexahedral, although various shapes, from trideral to octahedral, may also be seen.

An electron micrograph of a polyhedron (181)reveals a socket, also six-sided, in which the virus particles reside. The double shadowing technique has shown that the cytoplasmic virus of *A. mylitta* is icosahedral (53).

FIGURE 57. *A. mylitta* larva infected with polyhedrosis

Transmission: The most common mode of transmission is oral; but transovum transmission through surface contamination of the eggs laid by infected females has also been observed. The larvae contract the disease when they eat a portion of the eggshell during hatching.

Incidence: The estimated loss in rearings due to the disease is 25%. The loss is higher in the first rearing season than in the second, and in the third it is minimal. The incidence of mortality increases with age (167).

Predisposing factors: High humidity and temperature cause higher mortality from polyhedrosis. The natural epizootics of the disease were found to be more common in higher density populations (178). Feeding on tender, juicy leaves which are deficient in nitrogen increases susceptibility. Besides, an imbalance between nitrogen and carbohydrates in the food induces polyhedrosis.

10.2 Bacteriosis

The tasar silkworm suffers from three types of bacterial disease with three distinct symptoms (169).

Symptoms: Sealing of the anal lips (SAL) the larva first becomes restless. In about 12 hours it loses appetite and becomes sluggish. In another 12 hours it starts defecating a soil-coloured, sticky, semisolid excreta which solidifies on contact with air, sealing the anal lips completely (Figure 58). At this stage the larva stops feeding, becomes immobile and shrinks lengthwise. In another 8 to 10 hours it loses its grip on the twig and topples. The larva dies in another 24 hours.

Chain type excreta (CTE): The diseased larva is slightly thin, soft and sluggish and engages in limited feeding activity. In about 24 hours it starts to excrete a slimy substance along with the faeces, as a result of which chain of faecal beads hangs from the anal opening (Figure 59). The claspers lose hold of the twig, and the posterior half of the larva hangs obliquely. It remains in this position for about 12 hours before toppling and dying.

Rectal protrusion (RP): The infected larva becomes restless and sluggish. In 18 to 20 hours the rectum is protruded in the form of a transparent bag filled with green haemolymph (Figure 60). The anal lips dilate, feeding stops and the body contracts lengthwise. The larva remains attached to the twig for 6 to 8 hours before falling. It dies in another 24 hours.

FIGURE 58. *A. mylitta* larva with sealing of the anal lips

FIGURE 59. *A. mylitta* with chain type excreta

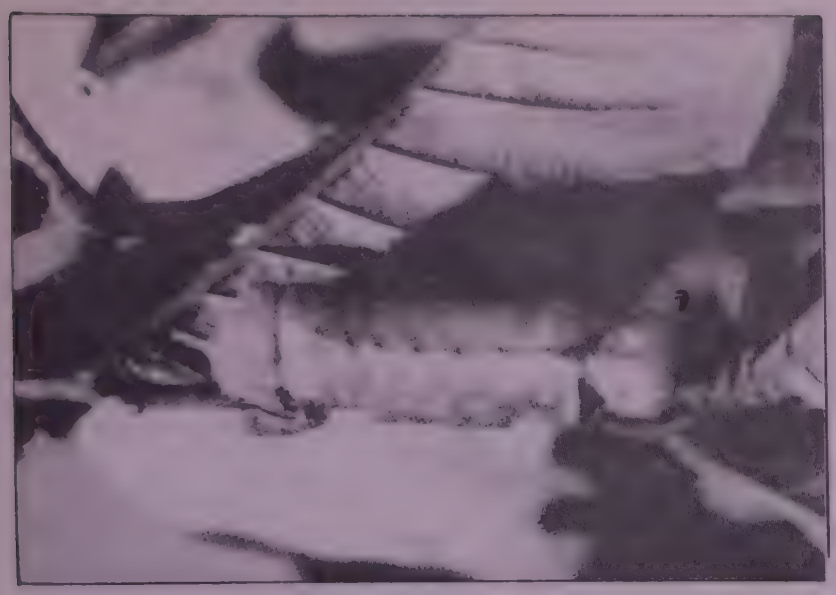


FIGURE 60. *A. mylitta* with rectal protrusion

FIGURE 61. *A. mylitta* after death from mycosis

Causative agent: Microscopic examination of the infected larvae reveals the presence of gram–negative micrococci (in singles and chains) and gram–positive bacilli (thin isolated rods and large rods in chain formation).

Incidence: Bacteriosis causes about 15% of larval mortality. Among the bacterial diseases, the incidence of SAL is highest (8%), followed by CTE (5%) and RP (2%). The incidence of bacteriosis is higher in the second rearing season than in the first (167), and it is almost negligible during third season; however, in all three rearing seasons the incidence ratio for SAL, CTE and RP remains nearly the same (60:30:10). As with virosis, the mortality rate increases with age.

Transmission: Bacteriosis is transmitted orally. There is no possibility of transovarial transmission. After proper disinfection the layings yield healthy progenies.

Predisposing factors: Among the different factor inducing the disease, the feeding of over–mature leaves to early instar larvae is significant. Bacterial infection, unlike virosis, is accelerated by lower temperature and relative humidity.

10.3 Mycosis

Symptoms: The larva suffering from mycosis becomes hard, pale and inactive about 12 hours after infection. This is followed by a characteristic dorsal bending of the body. In 6 to 8 hours it dies, and within 48 hours the corpse is covered with green, powdery spores. The dead speciments ultimately become laterally compressed, dry, hard, brittle and mummified (Figure 61).

Causative agent: Two types of fungi, *Penicillium citrinum* and *Paecilomyces varioti,* are the causative agents of mycosis. The spore of *P. citrinum* is globular and greenish grey; that of *P. variotti* is oval and green. The *in vitro* life cycle of these two pathogens (170) is 46 and 50 hours respectively (Figure 62).

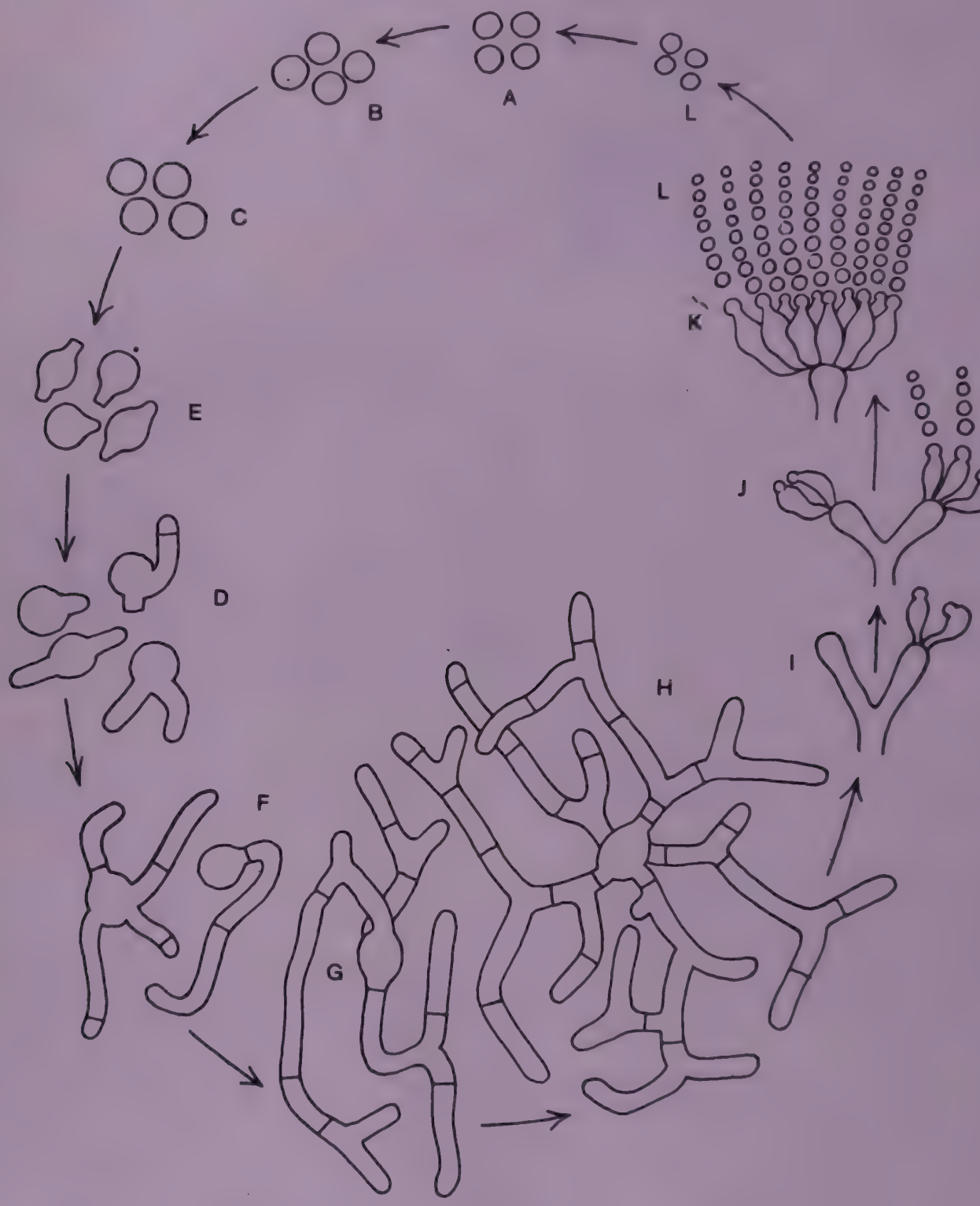


FIGURE 62. Development of *P. citrinum*

A, B, C - swelling of spores at 2, 6, 8 hours;

D - germination of spores at 10 hours;

E, F, G, H - development of vegetative bodies at 12, 14, 16, 18 hours;

I - development of fruiting bodies at 32 and 34 hours;

K - formation of conidiospores at 36 hours;

L - free conidiospores at 46 hours

Transmission: Mycosis is transmitted mainly through integumental injuries and the spiracles. After establishing itself on the integument of the larva, the spores germinate and radiate hyphal filaments which enter the body cavity and ramify inside the tissues. Attempts to reproduce the disease orally or transovarially have been unsuccessful.

Incidence: Mycosis appears early in the second rearing season (late August to early September); it is rare in the first rearing season and has not been observed in the third. The incidence, virtually nonexistent in the first two larval instars, occurs mainly in the third instar. The total loss is negligible.

Predisposing factors: Physico–physiological traumata, or wounds, and high humidity with a moderately high temperature are equally important contributing factors.

10.4 **Microsporidiosis — Symptoms:** Reduced feeding, sluggishness, a thin and darker body, black spots over the integument and stunted growth are the important symptoms of the disease (Figure 63). The black spots appear only after the second moult. The progenies of the infected brood exhibit disparity in larval growth and moulting.

Almost 90 to 98% of the infected larvae die. Even those which survive are noticeably debilitated (45, 204). The wings of infected adults are generally crumpled and their reproductive capacity is reduced (86). The scales become thin in density and adhere loosely.

FIGURE 63. Microsporidiosis in an *A. mylitta* larva

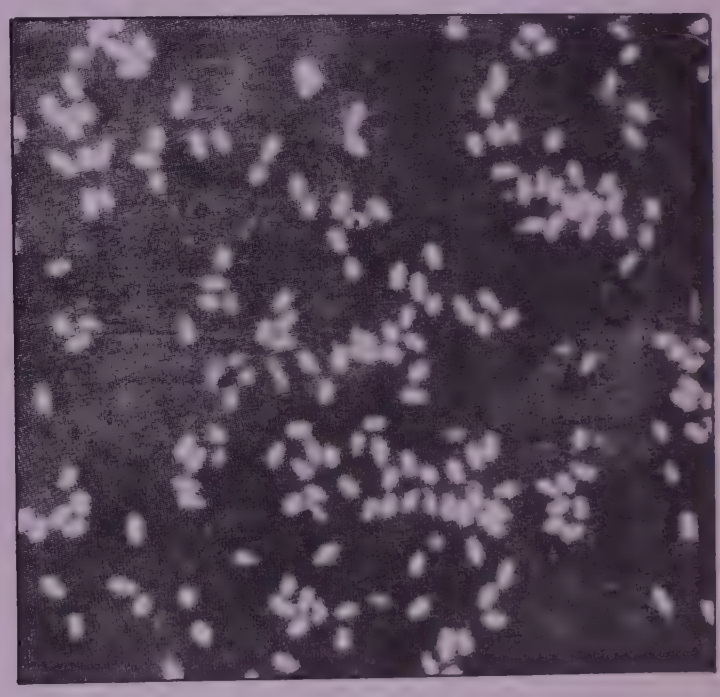


FIGURE 64. Microscopic field of *Nosema* spores causing microsporidiosis in *A. mylitta*

Causative agent: The disease is caused by a monosporoblastic microsporidian of the family Nosematidae and the genus *Nosema*. The spore measures 5.80 + 1.16 microns in length and 2.3 ± 0.46 microns in breadth (Figure 64). The pathogen invades almost all the tissues, including midgut epithelium, longitudinal muscle fibre, fat body, ovary, testis and haemocyte.

Transmission: The transmission of *Nosema* is oral, transovum and transovarial; however, transovum and transovarial transmissions are the most important modes of dissemination (86). The intensity

of infection in the offspring directly correlates with that in the mother moth (107, 140). The male moth cannot transmit the pathogen because the *Nosema* spore is bigger than the sperm head (Table 13).

Table 13: Comparative size of *Nosema* spores and sperm heads in *A. mylitta* (In microns)

Factor	Length			Width		
	Min.	Max.	Av.	Min.	Max.	Av.
sperm head	4 10	4 50	4 30	0.40	0.55	0.47
Nosema spore	4.64	6.96	5.80	1.86	2.78	2.32

10.5 Controls

The chance of infection can be reduced substantially by precautionary measures, including microscopic examination of the mother moths, disinfection of eggs and maintenance of aseptic conditions during grainage and rearing.

Microscopic examination is the most effective means of combating disease, especially if transmitted transovarially. For the preparation of disease-free layings a three-tier examination of the mother moths is recommended. Disinfection is also important for reducing the incidence of diseases. The eggs should be surface sterilized with 10% formalin for ten minutes and then followed by thoroughly washing in water (48); the rearing hut and equipment should be disinfected with 5% formalin.

Control of microsporidiosis: The control of microsporidiosis remains a major problem in tropical tasar culture. As the disease is transmitted transovarially, the Pasteur method of preparing disease-free layings is the best remedy; however, it is rather impracticable on traditional tasar tracts because the layings are generally prepared by unskilled workers. A feasible alternative is the cumulative heat treatment, twice each at the pupal (40°C for 8 hours) and egg (46°C for 5 minutes) stages (49). This treatment not only reduces infection by 80 to 85%, thus increasing the yield, but also helps improve the emergence and reproductive potential. It has also been observed that certain drugs, such as fumagillin and benomyl, are quite effective for microsporidiosis control.

Precautions in an epidemic: Of the four diseases of *A. mylitta* microsporidiosis is most fatal. The following precautionary measures should be adopted to combat the disease:

i) Seed cocoons should be procured only from uninfected areas (seed zones), and disease free layings should be selected on the basis of thorough microscopic examination.

ii) The transfer of cocoons from infected to uninfected areas should be prohibited and the cocoons from infected areas utilized solely for reeling.

iii) Smears of infected moths and larvae of infected lots, along with leaves plucked from that particular bush, should be burned and buried.

iv) Periodic surveys should be conducted at both the larval and the pupal stage to forecast the possibility of epidemic.

Chapter 11

PARASITES AND PREDATORS

The vulnerability of the tasar silkworm to certain parasites and many predators causes a 40 to 45% loss. The parasites are *Blepharipa zebina* and *Xanthopimpla pedator*. The more common predators are *Canthecona furcellata, Oecophylla smargdina, Hierodula bipapilla, Sycanus collaris* and *Polystes hebracus*. Its noninsect enemies include spiders, lizards, birds, snakes and a threadworm (*Hexamermis* sp.).

11.1 Life cycle and mode of infestation Parasites

Blepharipa zebina: The tachinid fly is parasitic to larvae and pupae of *A. mylitta* (65). A female tachinid lays 250 to 300 eggs, an average of 30 to 40 on a single host. Hatching takes place within three days of oviposition.

The maggots bore into the body of the larva. Black scars appear at the points of entry. The full-grown maggots, which are cream colour and 16 mm long, live 10 to 12 days. If infestation takes place late in the fifth instar, the larvae may still spin cocoons. The mature maggots come out by making holes in the cocoon shell after killing the pupae. The maggots pupate inside the soil. The pupa is nearly 12 mm long and dark brown.

The female and male flies are 14 and 12 mm respectively. The body is greyish with five longitudinal depressed lines on the dorsal shield of the thorax (Figure 65). The abdomen has four segments with two white transverse stripes.

Xanthopimpla pedator: Commonly known as ichneumon fly, it is an endoparasite of tasar pupa. The adult is about 2 cm long and has two pairs of transparent wings and a pair of prominent antennae. The insect is yellowish with a black spot dorsolaterally on each sternum, as well as four black spots on the pro-thoracic shield. The female fly has prominent needlelike ovipositor about 1 cm long with two identical stylets (Figure 66).

After copulation the female pierces the pupa through the cocoon shell with its ovipositor and lays a single egg. The maggot after hatching eats the insides of the pupa and pupates inside the remaining skin. The adult emerges by making a hole in the cocoon. A single female parasitizes many tasar worms.

FIGURE 65. Adult *B. zebina*

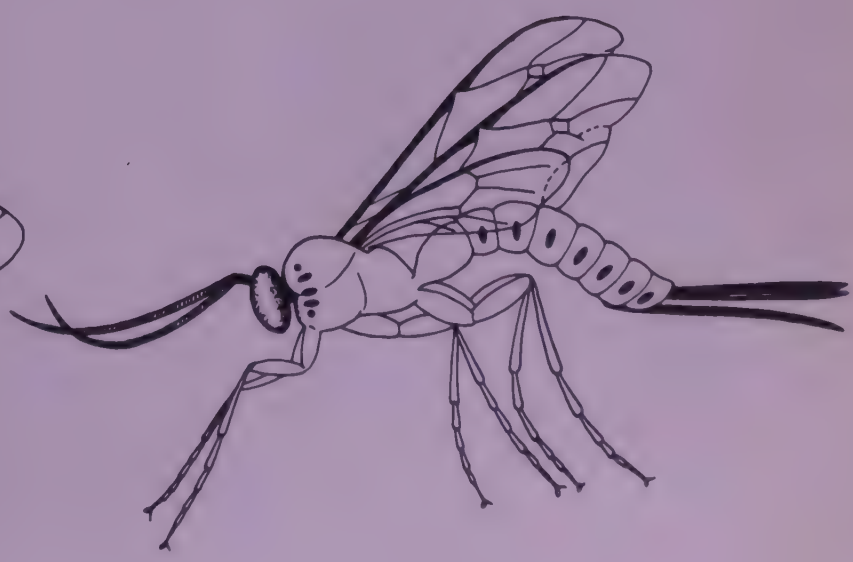


FIGURE 66. Adult *X. pedator*

Predators

Canthecona furcellata: The canthecona bug is the most harmful enemy of tasar silkworms. Each female lays 200 to 300 eggs in batches of 40 to 70. The freshly laid eggs (Figure 67) have a metallic lustre, at first silvery and later coppery. They hatch in about 6 days. The entire nymphal period is about 18 days (172). The adult is about 15 mm long and has a life span of 13 to 19 days.

The predator lives on the haemolymph of the host, which it sucks by piercing the larval body. A single bug can kill 130 to 220 tasar first – to third–instar larvae in its life span.

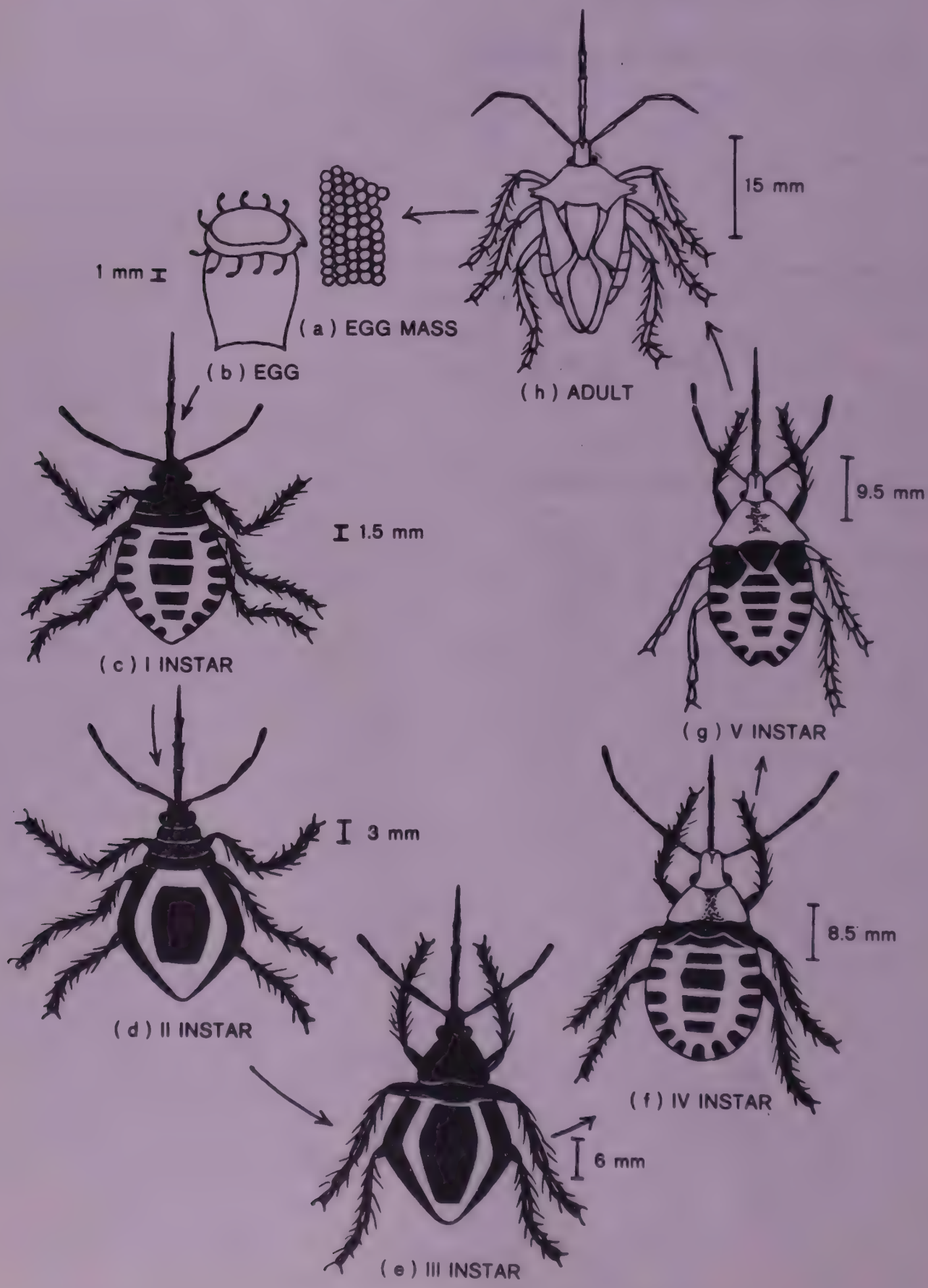


FIGURE 67. Life cycle of *C. furcellata*

Oecophylla smargdina: The red ant, a social insect, lives in primary and secondary nests made of leaves. The colony consists of workers (reserve force, defenders and nurses) and sexuals (males and females) with a clear-cut division of labour (54). Two types of eggs are laid (112): the small ones giving rise to queens and workers, the larger ones to males (Figure 68).

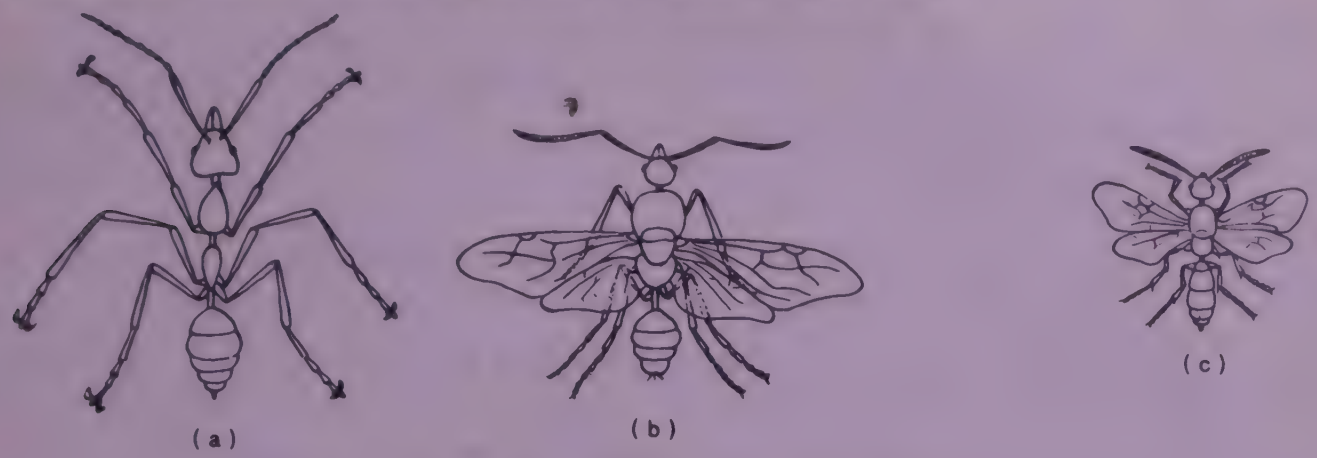


FIGURE 68. *O. smargdina* (a) male, (b) female, and (c) worker

The adults of the first brood are workers. They are quite small because of the limited food supply during their development. They open the chamber and search for food; then the care of the colony is completely taken over by them. The adults produced subsequently are larger than those of the first brood. After some time, sexuals are produced and mass mating takes place, resulting in a large multiplication of the predator.

The predators generally attack in groups and carry the young larvae to their nests. They attempt to feed on the appendages including hairs and setae, of the advanced-stage larvae by biting. This causes swelling, paralysis and eventual death of the larvae.

Hierodula bipapilla: The carnivorous praying mantis occurs throughout the tropics. The eggs are laid in oothecae, which are attached to the plants.Each ootheca, about 2.5 cm long, contains about 24 egg chambers. A female produces a number of oothecae (21). The number of nymphal instars varies from four to six. The adult is large (5–8 cm) and green; it is easily recognized by its peculiar raptorial forelegs (Figure 69).

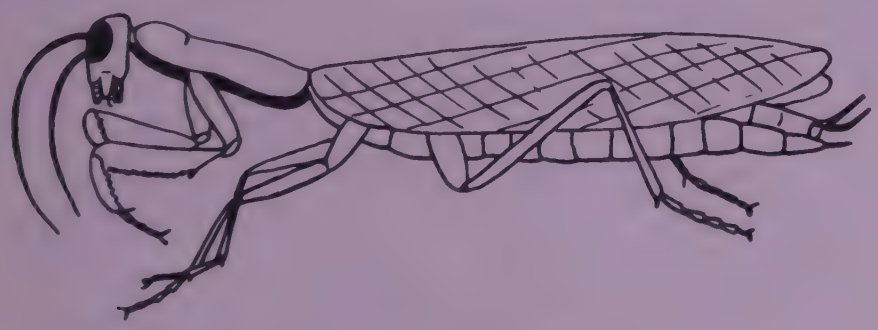


FIGURE 69. Adult *H. bipapilla*

FIGURE 70. Adult *S. collaris*

Nymphs and adults carry away the first and third-instar which are easy to feed on. They can only inflict injury on the fourth and fifth-instar larvae, which die, however, if the injury is deep.

Sycanus collaris: The common reduviid bug lives under any shelter or on plants. The eggs are laid mostly under stones or bark. The eggs hatch within 4 to 5 days of oviposition. There are five nymphal instars. The adult is black and about 2.5 cm long (Figure 70). The rostrum consists of three segments, and the antennae are filiform. The head is long and conical. The prothorax is narrow. Like C. furcellata, it sucks the larval haemolymph with its long (6–8 mm) proboscis. Early-instar larvae are more likely to be attacked by this predator.

11.2 Incidence and damage

The most damage is caused by *C. furcellata* (13%), followed by losses due to *B. zebina* (8%) *O. smargdina* (7%), *X. pedator* (5%), *H. bipapilla* (5%) and *S. collaris* (2%). Of the 40 to 45% loss of larval due to pests, nearly 30% occurs during the first three instars.

The incidence of *C. furcellata* and *H. bipapilla* is highest in September and October (Figure 71). *O. smargdina* occurs throughout the year with about the same intensity. *B. zebina* appears at the beginning of October and disappears by the end of November. The incidence of *X. pedator* is observable November–January and that of *S. collarie* August–October.

11.3 Controls

The new rearing techniques have considerably reduced the losses incurred by parasites and predators. Pest control is still a problem however, because a major part of the rearing is conducted outdoors.

The application of insecticides is not practicable due to their harmful effect on tasar silkworm. Constant vigilance is the only effective remedy. Certain cultural methods also help reduce the incidence of pests. To control the incidence of tachinid fly, the cocoons of the infested larvae should be isolated and stifled before the maggots pierce the cocoons. This will also save the cocoons before they become unreelable. Collection and destruction of the oothecae of *H. bipapilla* the eggs of *C. furcellata* and the nests of *O. smargdina* will greatly help reduce those populations.

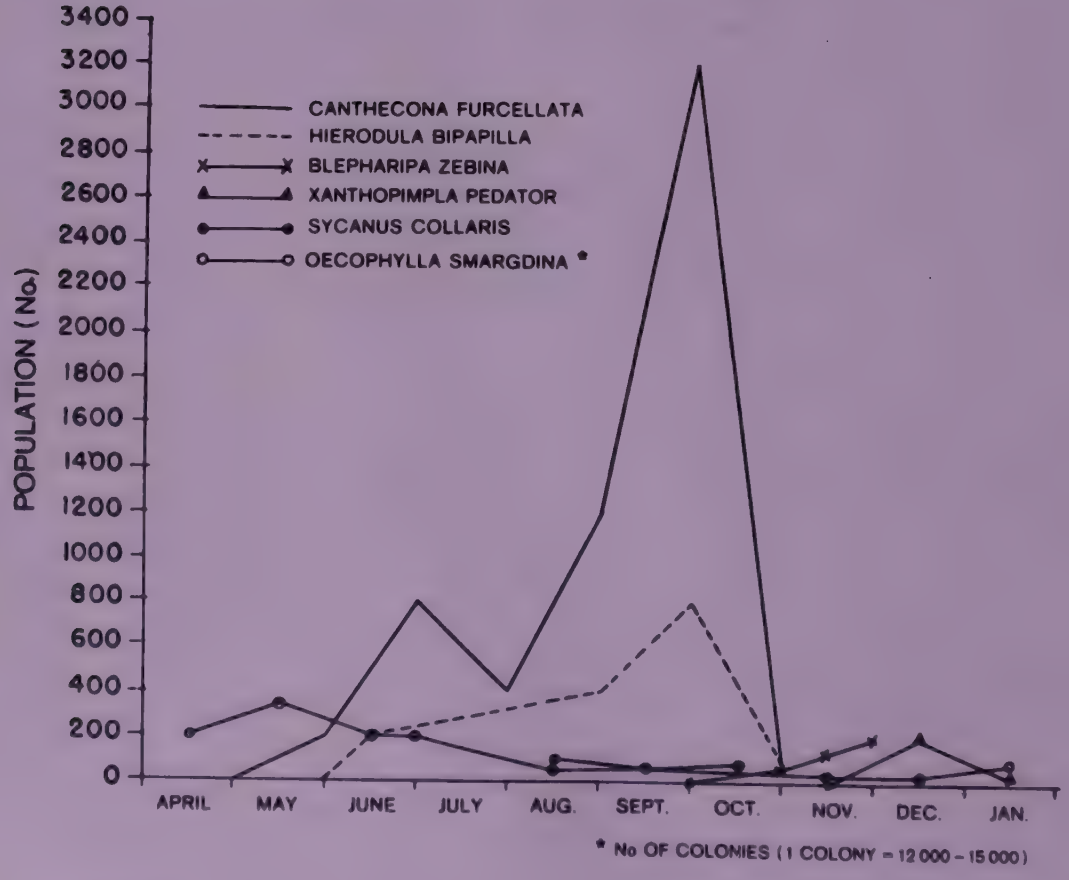


FIGURE 71. Incidence of parasites and predators in *A. mylitta*

Chapter 12

SILKWORM BREEDING AND GENETICS

Bredding and genetics are recent off-shoots of tasar culture. The sericulturists have concerned themselves mainly with analysis of the breeding and genetic potential of the tasar fauna and an understanding of its genetic architecture so as to offer a rich breeding base with a broad genetic spectrum. Consequently, substantial headway of immediate economic interest to the industry has been made.

12.1 Genetic and breeding potential of *A. mylitta*

Owing to free interbreeding in nature for centuries the *Antheraea* fauna is highly heterogeneous, which makes it very potent material for breeding and genetics. The twenty-five eco-races of *A. mylitta* D. alone (Table 14) reveal interesting variabilities (68). The degree of variability is illustrated in Table 15

Table 14. Commercial characters of the eco-races of *A. mylitta* D.

Ecotype	Food plant	Peduncle length (cm)	Cocoon volume (cc)	Cocoon weight (g)	Pupal weight (g)	Shell weight (g)	Silk ratio (%)	Filament length (m)	Denier
Daba (Bihar)	*Termi-nalia*	4.80	32.31	12.10	10.57	1.53	12.64	750	12
Laria (M.P.)	"	5.38	17.34	9.75	7.87	1.88	19.28	785	10
Daba (M.P.)	"	4.70	30.40	11.16	9.96	1.20	10.75	737	12
Bhandara	"	5.89	12.09	6.93	5.69	1.24	17.89	613	9
Sarihan	"	4.47	14.32	6.89	6.18	0.71	10.30	533	9
Nega	"	5.00	15.30	7.74	6.51	1.23	15.89	819	8
Bogai	"	5.50	19.20	9.42	7.97	1.45	16.34	895	9
Jadie	"	4.00	29.50	12.29	10.06	2.23	18.14	995	12
Moonga	"	4.53	15.28	7.73	6.49	1.24	16.04	834	9
Nowgaon	"	4.00	18.00	8.60	7.36	1.24	14.30	475	10
Andhra	"	6.20	21.00	9.45	7.88	1.57	16.61	700	10
Nalia	*Shorea*	11.34	25.58	11.68	9.11	2.57	22.00	1 201	12
Raily	"	7.82	30.36	12.77	10.11	2.66	20.83	1 232	13
Mugia	"	4.31	20.93	11.11	8.74	2.37	21.33	1 239	11
Mirzapur (U.P.)	"	4.50	20.00	8.14	6.50	1.64	20.14	800	11
Barharwa	"	6.05	27.40	13.76	10.75	3.01	21.87	1 234	12
Modia	"	5.70	32.39	15.29	12.12	3.17	20.73	1 234	12
Modal	"	6.37	31.35	14.17	10.53	3.64	25.68	1 383	12
Laria (Bihar)	"	4.50	17.30	8.40	7.20	1.20	14.28	7[illegible]	10
Patjharia	"	4.40	16.20	7.32	6.38	0.94	12.84	895	9
Jarui	*Lager-stroemia*	3.80	13.40	6.37	5.27	1.10	17.26	600	8
Munga (W.B.)	"	6.80	13.00	6.86	5.97	0.89	12.97	550	10
Southern Viet Nam	"	4.50	10.00	5.80	5.20	0.60	10.34	550	9
Giribam	*Zizy-phus*	4.50	16.00	11.31	8.77	2.54	22.44	950	10
Belgaum	*Hard-wickia*	5.00	12.50	6.38	5.84	0.54	8.46	617	

by the heterogeneity of quantitative, qualitative and physiogenetic characertistics of the most popular eco-race, Daba.

Table 15. Heterogeneity in Daba (*A. mylitta* D.)

A. Quantitative characteristics

Season	Range	Eggs/ laying	Hatch-ing	Cocoon Weight (g)		Shell Weight (g)		Shell ratio (%)		Filament length
		(No)	(%)	Male	Female	Male	Female	Male	Female	(m)
	Min.	86	53.89	8.00	8.60	0.90	1.00	10.20	8.00	243
I	Max.	330	92.38	12.04	16.00	1.70	2.30	17.50	15.50	1 000
	Av.	176	66.68	10.00	13.00	1.00	1.46	11.50	9.50	700
	Min.	135	56.47	8.80	9.70	1.10	1.30	12.50	10.40	700
II	Max.	400	97.59	15.20	20.30	2.25	3.15	19.10	17.00	1 400
	Av.	220	74.00	12.20	15.40	1.80	2.40	16.00	14.00	800

B. Physiogenetic characteristics

Factor	Season	Average span in days				
		Emergence	Oviposition	Embryonic period	Larva	Spinning
Entire rearing	I	35	40	48	50	20
Single laying		9–10	5–6	16	30–50	15–20
Entire rearing	II	40	46	55	60	35
Single laying		14–15	6–7	16	35–60	20–25

C. Qualitative characteristics

Character	Variation
Egg colour	Brownish, creamy, bluish, white
Larval body colour	Green, yellow, blue, almond
Lateral tubercle colour	Dark violet, light violet, white
Dorsal shining spots:	
Colour	Brick red, white
Frequency	Plain, regular spotting (1:1–6:6), irregular spotting
Prothoracic hood marking	Red, white
Cocoon colour	Grey, yellow
Moth colour	Yellow, grey, brown

12.2 Breeding

Selection and hybridization are common practice in tropical tasar culture.

Germ plasm bank: The gathering and maintenance of genetically diverse populations are the essential elements of breeding work. A rich germ plasm bank is maintained for tropical tasar. It contains six acclimatized eco-races, twenty pure inbred lines, three mutant races and twelve new segregants. Mass selection and breeding are being applied for stock maintenance.

Selection

Qualitative selection: Three larval body-colour mutants have been isolated from the natural population of *A. mylitta* (Daba) and fixed through individual selection and line breeding. The mutants, which now have the status of race, are designated CTRS Yellow (67), CTRS Blue (66) and CTRS Almond (70).

The wild type is green. In addition, twelve new segregants of Daba have been established with different combinations of characteristics, including cocoon colour, tubercle colour and frequency of lateral shining spots.

Quantitative selection: In view of the existing variabilities in *A. mylitta,* the range of selection for characteristics is ample (173). Some strains of Daba are already in the process of fixation through mass and family selections for higher fecundity; for cocoon weight and shell ratio, for uniform development, for shorter larval span and for other characteristics.

Hybridization

Inbreeding: Because of the high heterogeneity in the races of *A. mylitta,* pure line breeding is a prerequisite of hybridization. So far twenty pure lines have been produced from three isolated populations of Daba by brother-sister mating. Inbreeding of Raily, Laria and Barharwa has been introduced with the objective of evolving lines from genetically diverse populations.

The inbred lines of Daba were tested for general combining ability (GCA) and specific combining ability (SCA) at the sixth and the twelfth generation of inbreeding (81). Of the twenty lines, about ten are good combiners.

Interregional hybridization: Among the crosses between Daba and the acclimatized eco-types (Barharwa, Laria, Raily and Modal), Daba x Raily and its reciprocal show heterosis to the extent of 50% over mid-parent value (Figure 72). This cross combination with the acclimatized stocks has been recommended for commercial exploitation.

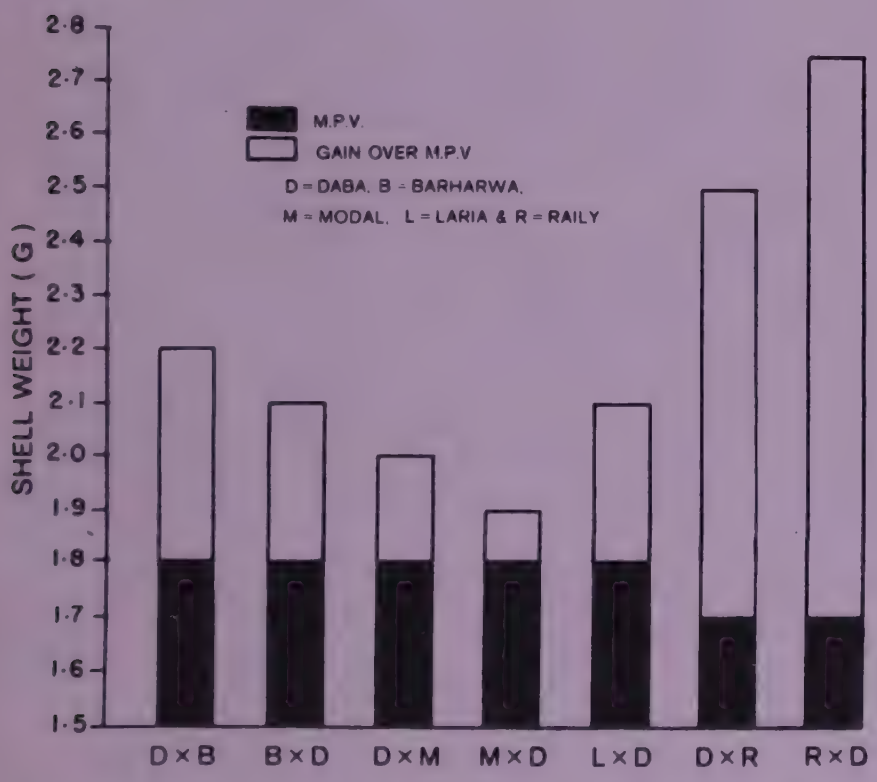


FIGURE 72. Gain in shell weight over mid-parent value (M.P.V.) in the hybrids of eco-races

FIGURE 72. Gain in shell weight over mid-parent value (M.P.V.) in the hybrids of eco-races.

Interracial hybridization: Single three-way and double crosses have been tried with four races. Daba Green (G), CTRS Yello (Y), CTRS Blue (B) and CTRS Almond (A).

Single crosses: Heterosis was recorded in all the characteristics studied (hatching, coccon and shell weights, shell ratio and E.R.R.) regardless of the cross combination; however, the effect was more pronounced in sheel weight, particularly in B × Y, A × B and A × G (Figure 73a). In diallel analysis the

component of genetic variance recorded was overdominance for all the characteristics (69). The other components were additive genetic variance, epistasis and, in some cases, complementary gene action.

Three-way crosses: Of the two characteristics considered for three-way crosses — cocoon weight and shell weight — the latter scored comparatively higher heterosis over mid-parent value. G x AY, G x BY, B x AY and B x YG were found to be better combinations (Figure 73b) Triallel analysis showed the presence of additive gene action in cocoon and shell weights (85).

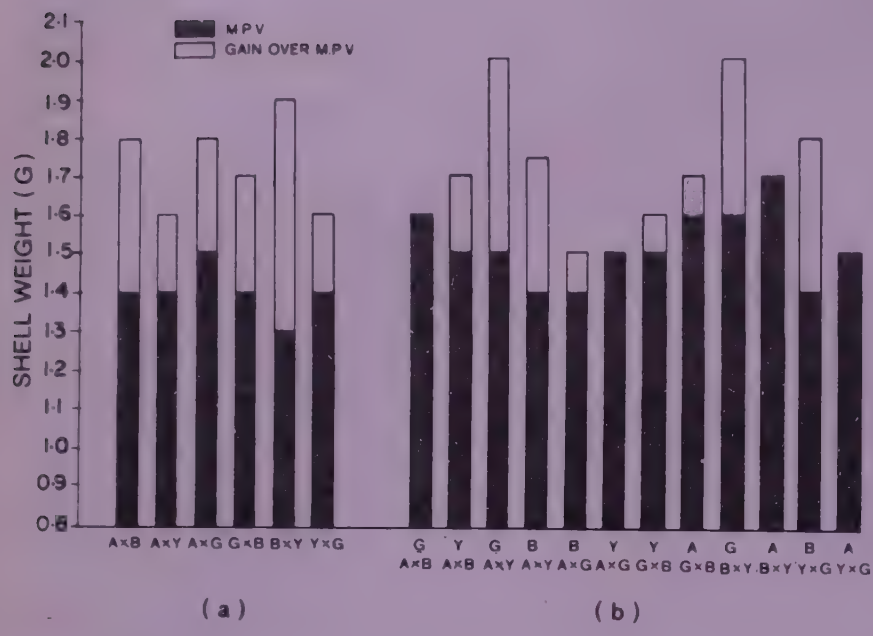


FIGURE 73. Heterosis in relation to mid-parent value (M.P.V.) in (a) single and (b) three-way crosses

Double crosses: Only three double crosses were tried: BG x YA, YB x GA and YG x BA. They revealed average superiority over mid parent value for all selected characters: fecundity, larval weight, cocoon weight, shell weight and shell ratio. Significant improvement in fecundity was noticed in the double cross as well as in the three-way cross with a mother parent of hybrid origin (11). This indicates that double hybrids or similar polyhbrids are highly desirable for commercial crops. This approach can be used for highly productive races with comparatively low fecundity.

In this summary of the studies so far made on different systems of crossing *A mylitta* the gene action is complex, involving epistasis or additivity and both in some cases. Nonallelic interaction may be present where there is overdominance (60).

Interspecific hybridization: Four species have been hybridized with *A. mylitta: A. pernyi, A. roylei, A. frithii* and *A. sivalica.* In the crosses and reciprocals with *A. pernyi* or *A. roylei* either the eggs did not hatch or the few larvae hatched failed to survive beyond the first instar. Whereas crossings with *A. frithii* produced healthy F1 progenies, the adults were sterile. Only *A. mylitta* x *A. sivalica* and reciprocal resulted in fertile hybrids. Attempts are being made to overcome the sterility barrier in the hybrids of *A. mylitta* and *A. frithii* through amphidiploidy, back crossing or parthenogensis.

12.3 Genetics

Inheritance of larval body colour:

Earlier observations on inheritance of larval body colours in *A. mylitta* put forward a digenic concept (70, 75). It was later confirmed, however, that three sets of genes are involved in the expression of body colours (88). Green is governed by $\overset{+}{y}$, $\overset{+}{b}$ and $\overset{+}{s}$. For yellow the presence of $\overset{+}{y}$ alone is sufficient, whereas Blue requires $\overset{+}{b}\overset{+}{s}$ as well. Almond is expressed in three ways: $yb\overset{+}{s}$, $y\overset{+}{b}s$ and ybs. The trigenic homozygous constitutions of the body colours are:

Green	yybbss	Blue	yybbss
Yellow	yybbss, yybbss, yybbss	Almond	yybbss, yybbss, yybbss

Pleiotropism: Table 16 shows the relationship in *A. mylitta* between the colours of the larval body (LB) and those of the prothoracic hood markings (PHM), the dorsal shining spots (DSS) and the lateral tubercles (LT).

Table 16. Colour relationship of LB to PHM, DSS and LT in *A. mylitta*

LB	PHM	DSS	LT
Green	Red	Brick red	Deep violet
Yellow	Red	Brick red	White, deep violet, light violet
Blue	White	White	Deep violet
Almond	White	White	White, deep violet light violet

These colour characters are so closely associated that they do not produce recombinant types in either experimental or natural populations.

It has been confirmed that the genes responsible for the expression of larval body colours (y, b and s) are pleiotropic. Thus the gene y governs not only the body colour, but also the colour of the prothoracic hood markings (PHM) and the dorsal shining spots (DSS), whereas the colour of the lateral tubercles (LT) is governed by genes b and s (Figure 74).

These characters have the following genetic mechanism:

Brick red DSS and red PHM	yy/yy
White DSS and white PHM	yy
Deep violet LT	bbss/bbss/bbss bbss/bbss/bbss
White LT	bbss/bbss
Light violet LT	bbss

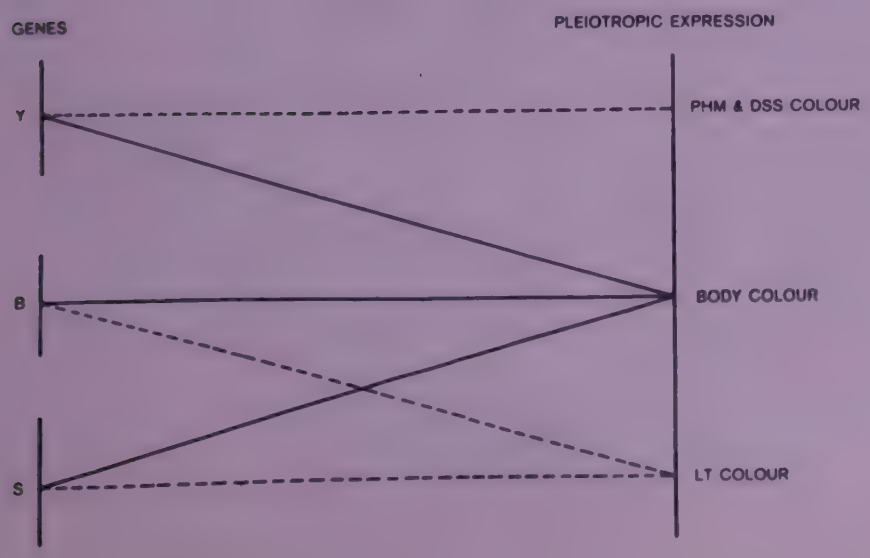


FIGURE 74. Diagram showing the mechanism of pleiotropism in *A. mylitta* D

Inheritance of cocoon colour: The cocoons of *A. mylitta* (Daba) are predominantly grey and yellow. Crosses and reciprocals of homozygous lines of grey and yellow cocoons reveal that this trait is governed by a single pair of alleles — the grey being dominant over the yellow.

Inheritance of moth colour: —Colour polymorphism in *A. mylitta* (Daba) is more or less limited to the female moths. The females are generally grey and yellow, and the males are usually brown; however, brown females and grey and yellow males occur occasionally. The moth colour in A. mylitta (Daba) appears to be sex limited and controlled, exhibiting polymorphism only in the females. The infrequent occurence of grey and yellow males and brown females is probably caused by a rare genetic condition that allows the genes in the respective sexes to express what would otherwise remain suppressed. Almost equal frequencies of grey and yellow females reflects balanced polymorphism.

12.4 Cytology

Cytological investigations have been carried out on fifteen eco-races of *A. mylitta* (177, 100): Jadie, Bogai, Jira, Moonga, Barharwa, Daba (Figure 75a), Sarihan, Moogia, Patjharia, Laria, Modal, Raily, Giribam, Belgaum and an eco-race from southern Viet Nam (Figure 75b). The studies did not establish any numerical variability between the eco-races. The polar view (metaphase I) of all the eco-races revealed 31 bivalents, which suggests that they are essentially monobasic.

The chromosome configuration of the F1 hybrids of *A. mylitta* (n=31) and *A. frithii* (n=31) was found to be 62, or the sum of the haploid numbers of the parental species. This is attributed to the lack of synaptic apptitude. However, as some cells show a pairing tendency, the cause of sterility in the hybrid is a lack of genetic compatibility.

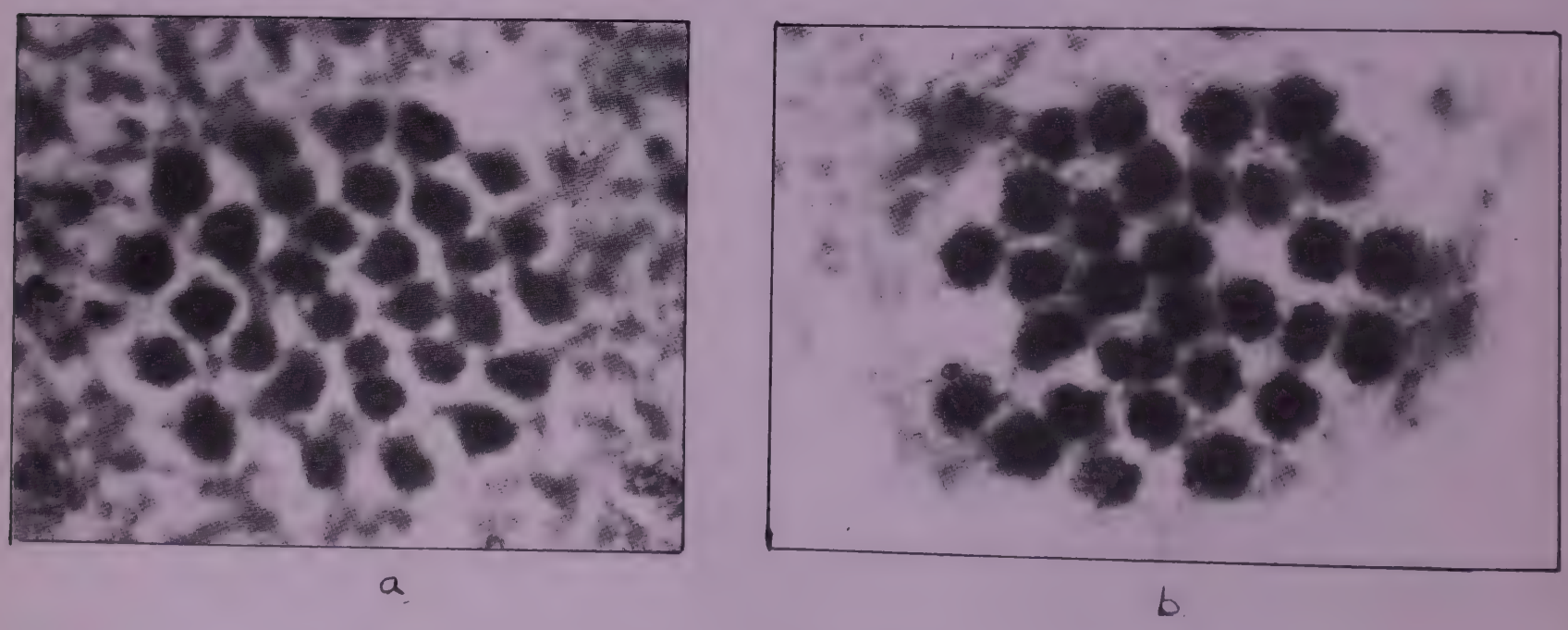


FIGURE 75. Chromosomes of *A. mylitta* (polar view of metaphase I):
(a) Daba (n = 31); (b) Southern Viet Nam (n = 31)

Chapter 13

TAXONOMIC ASPECTS OF ANTHERAEA

Recent studies on the morphology, cytology and interspecific hybridization of eight *Antheraea* species have revealed interesting features which may be significant taxonomically or phylogeneticaly. The species studied were *A. mylitta* D., *A. assamensis* Ww., *A. roylei* Mr., *A. frithii* Mr., *A sivalica* Mr., *A.. yammamai* G.M., *A. polyphemus* Cram. and *A. pernyi* G.M. The different observations made are discussed in this chapter.

13.1 Follicular imprints on the eggshell

Though the egg characters once served as the basis of Lepidopteran classification (24, 193), the impressions of the ovarian follicular cells over the allantochorion (183, 13) were not given due weight. The first systematic study of follicular imprints was made with the genus *Antheraea* (72, 93).

Morphologicaly the eggs of the different species can be grouped under three categories: 1) streaked, as in *A. mylitta, A. frithii* and *A. sivalica* (Figure 3); 2) streakless, as in *A. pernyi, A. roylei, A. assamensis* and *A. yamamai;* and 3) partially streaked as in *A. polyphemus.*

In the streaked eggs the follicular imprints show three distinct zones (Figure 76), whereas in the streakless and the partially streaked eggs the surface pattern is uniform throughout.

The interesting revelation of the study is the species specificity, both qualitative and quantitive, of the imprints of the disk zone (Figure 77, Table 17).On the basis of the shape of the main cells,the imprints can be broadly divided into four types: 1) round, as in *A. mylitta;* 2) oval, as in *A. pernyi* and *A. assamensis;* 3) polygonal as in *A. sivalica, A. frithii, A roylei* and *A. polyphemus* and 4) irregular, as in *A. yamamai.*

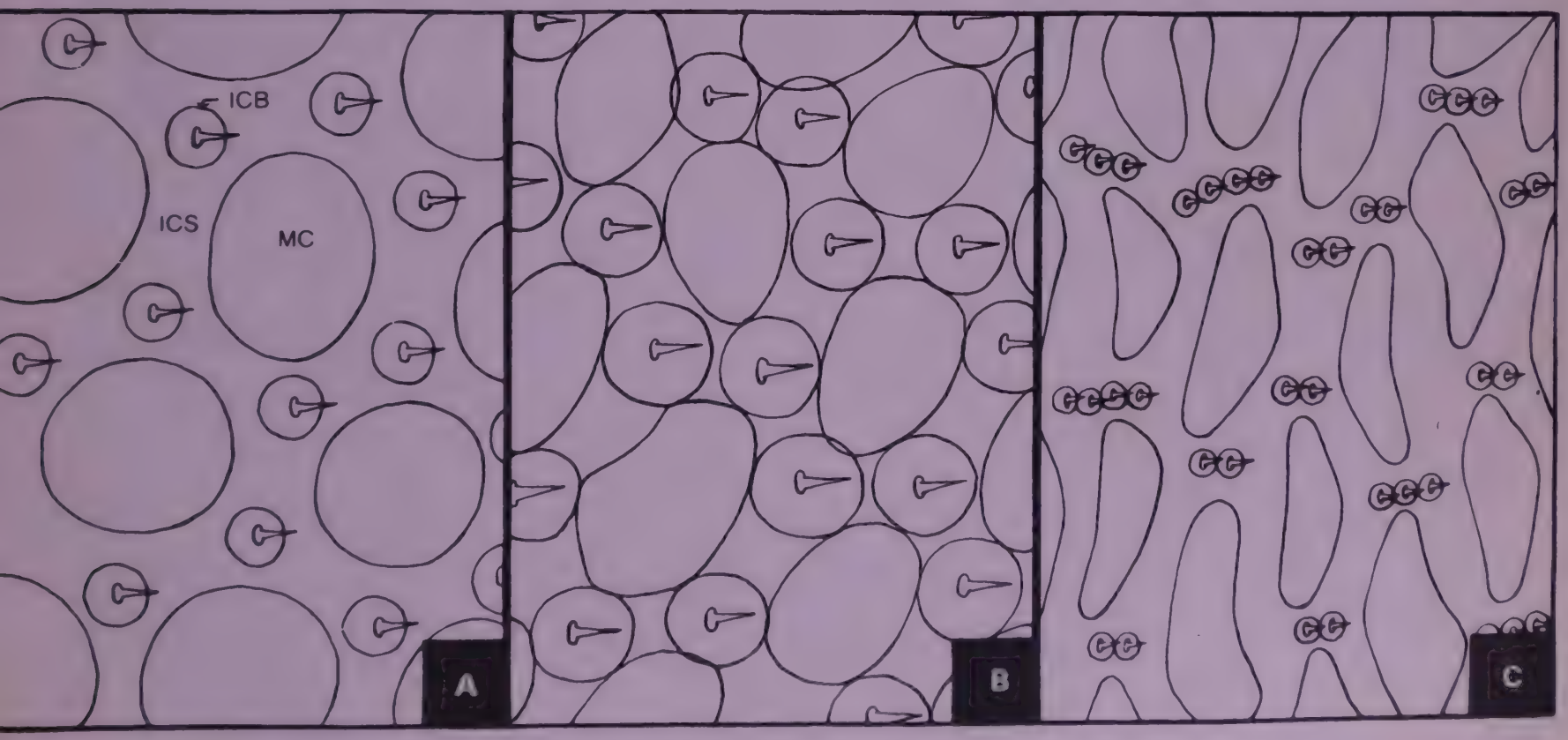


FIGURE 76. Follicular imprints on the egg of *A. mylitta* showing the (a) disk, (b) streak and (c) edge zones

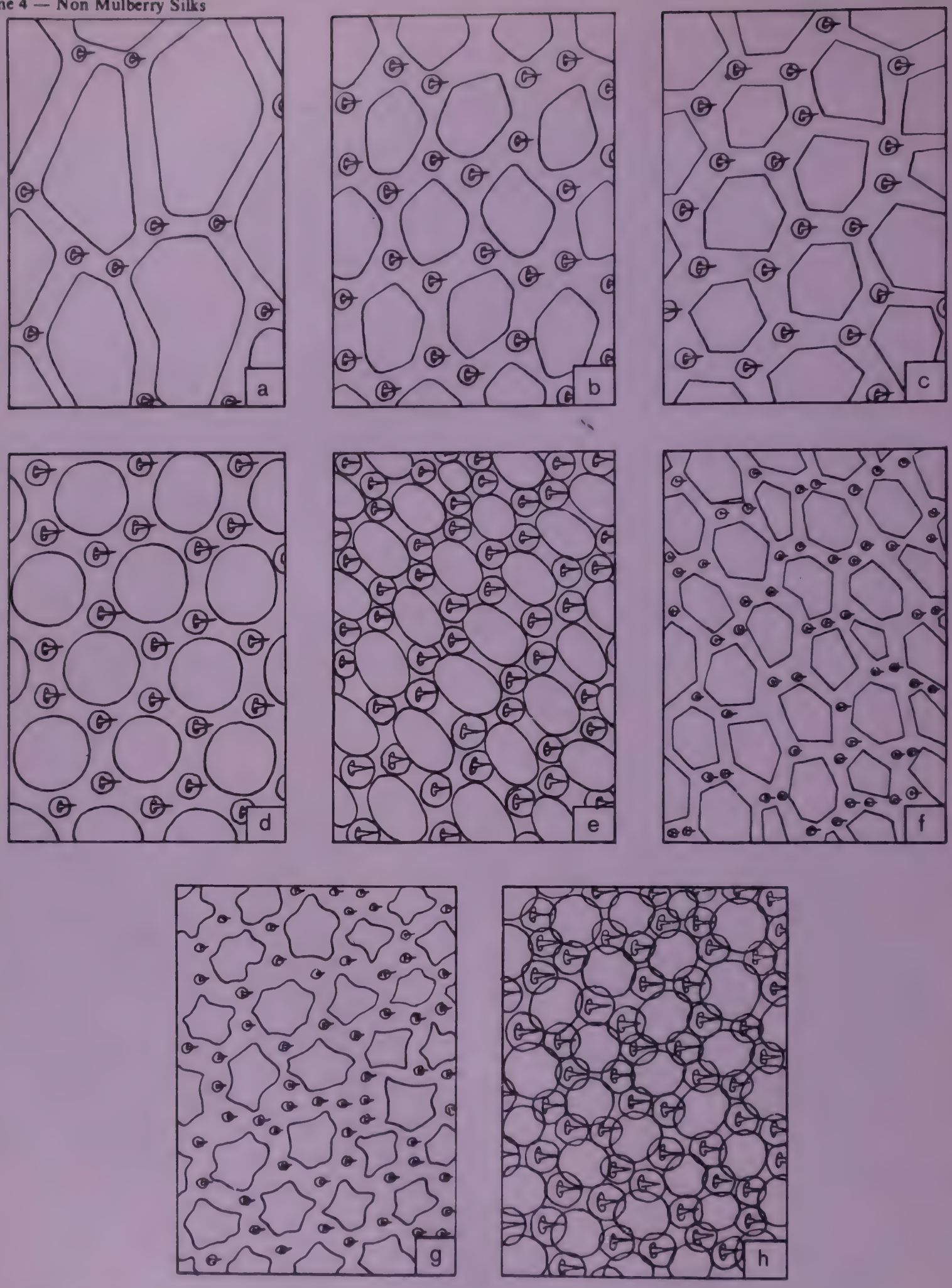


FIGURE 77. Variation in the disk zone pattern of follicular imprints in *Antheraea* species:

(a) *A. roylei*, (b) *A. frithii*, (c) *A. sivalica*,
(d) *A. mylitta*, (e) *A. pernyi*, (f) *A. polyphemus*,
(g) *A. yamamai*, (h) *A. assamensis*

Table 17. Mean, C.D. and C.V. of cell structures of follicular imprints in *Antheraea* species

Species	Area of M.C. * (mm^2)	Area of I.C.B. ** (mm^2)	Breadth of I.C.S. *,** (mm)
A. roylei	1 961.60	19.96	10.42
A. frithii	818.32	34.18	11.42
A. sivalica	811.10	35.38	9.86
A. mylitta	613.24	40.46	11.74
A. pernyi	408.90	96.52	7.10
A. polyphemus	368.10	3.69	5.92
A. yamamai	325.22	12.62	9.36
A. assamensis	213.96	68.30	5.54

* M.C. = main cell
** I.C.B. = intercellular body
*,** I.C.S. = intercellular space.

13.2 Tubercular setae

A classification of Lepiodoptera based on setaeferous tubercles was proposed long ago (39). The variation in setal arrangement in the advanced groups of Lepidoptera has been studied by many researchers (43, 55, 131, 142); however, the first attempt to study the tubercular setae in Lepidoptera through detailed investigations of eight *Antheraea* species has been made only recently (76, 92). Five types of tubercles are found in all these species (see Chapter 4, Section 2.2). The structure, arrangement and number of setae on the different tubercles in the third instar are presented by species in Figure 78.

The observations throw some light on the possible relationship between the species. The total number of setae is the same (462) in *A. pernyi, A. roylei, A. assamensis* and *A. polyphemus* and very close in *A. mylitta* (502), *A. sivalica* (502) and *A. frithii* (506). The eight species can be divided into two groups by shape of setae: 1) pointed, as in *A. assamensis, A. polyphemus, A. mylitta, A. sivalica* and *A. yamamai;* and 2) knobbed and pointed as in *A. roylei* and *A. pernyi.* The arrangement of the setae is more or less identical in all the species except *A. polyphemus.*

It is noteworthy that *A. roylei* and *A. pernyi* show a remarkable degree of resemblance in all features. *A. assamensis* is unique in resembling *A. mylitta, A. sivalica, A. frithii* and *A. yamamai* for structure of setae and *A. roylei* and *A. pernyi* for number of setae. *A. polyphemus,* while resembling *A. assamensis* for number of setae, has a distinctive arrangement of setae on some of the tubercles.

13.3 Wing venation

The basic pattern of wing venation in *Antheraea* has already been described under morphology of *A. mylitta* (Chapter 4). Differences among the eight species have been observed mainly in the structure of the median crossvein (Mc) and its alignment with the media bases A_1 and A_2. There are four types of Mc: 1) convex, as in *A. pernyi* and *A. roylei;* 2) concave, as in *A. polyphemus* and *A. yamamai;* 3) wavy, as in *A. mylitta, A. sivalica* and *A. frithii,* and 4) straight, as in *A. assamensis.* In *A. pernyi, A. roylei* and *A. yamamai* only A_2 joins Mc, whereas in *A. frithii, A. mylitta, A. sivalica, A. polyphemus* and *A. assamensis* none of the bases touches Mc (Figure 79).

TUBERCLE	SEGMENT	ANTHERAEA SPECIES							
		ROYLEI	PERNYI	ASSAMENSIS	POLYPHEMUS	MYLITTA	SIVALICA	FRITHII	YAMAMAI
DORSAL	PROTHORACIC HOOD								
	THORAX 2 & 3								
	ABDOMINAL 1 - 7								
	ABDOMINAL 8 th								
	ABDOMINAL 9 th								
	ABDOMINAL 10 th								
UPPER LATERAL	THORAX 2 & 3								
	ABDOMINAL 1 - 2								
	ABDOMINAL 3 - 8								
	ABDOMINAL 9 th	—	—	—		—	—	—	—
LATERAL	THORAX 1								
	THORAX 2 - 3								
	ABDOMINAL 1 - 8								
	ABDOMINAL 9 th				—				
LOWER LATERAL	THORAX 1								
	THORAX 2 & 3								
TOTAL		462	462	462	462	502	502	506	432

FIGURE 78. Structure, arrangement and number of tubercular setae in *Antheraea* species

13.5 Interspecific hybridization and chromosomal homology

Attempts to obtain interspecific hybrids of *Antheraea* have proved very useful for ascertaining the degree of genetic affinity and the possible phylogenetic relationship between the tested entities. The fourteen crosses and reciprocals effected between seven *Antheraea* species are listed with results in Table 19.

The only two fully fertile cross combinations were *A. pernyi x A. roylei, A. mylitta x A. sivalica* and reciprocals. The result of the combination of *A. pernyi* and *A. roylei* indicates that the high degree of compatibility between the chromosomes of these two species, despite a considerable difference in number (see Table 18), leads to regular synapsis (90). Considering also the evidence from the cytological observations, it is possible that *A. pernyi* originated from *A. roylei* through chromosomal fission (192), in view of the different chromosome numbers observed in separate populations of *A. roylei* (n = 30, 31, 32 and 34). *A. mylitta* and *A. sivalica* resemble each other in so many aspects, including chromosme number, that *A. sivalica* is often considered a variant or synonym of *A. mylitta*. The partial fertility (F_1) of *A. yamamai x A. pernyi* and *A. mylitta x A. frithii* indicates a close relationship between these species and a parallel course of evolution.

Table 19. Interspecific crosses and reciprocals of seven *Antheraea* species

Crosses and reciprocals	Results
A. pernyi x A. roylei	Fertile
A. roylei x A. pernyi	"
A. mylitta x A. sivalica	"
A. sivalica x A. mylitta	"
A. mylitta x A. frithii	F_1 sterile
A. frithii x A. mylitta	"
A. yamamai x A. pernyi	"
A. pernyi x A. yamamai	"
A. mylitta x A. pernyi	Sterile
A. pernyi x A. mylitta	"
A. mylitta x A. roylei	"
A. roylei x A. mylitta	"
A. mylitta x A. assamensis	"
A. assamensis x A. mylitta	"

Chapter 14

BIOCHEMISTRY

The biochemical aspects of *A. mylitta* have been studied at length. This chapter reviews the findings.

14.1 Chemical composition of diets

The food plants of A. mylitta vary from one another in chemical constituents (1,109,179). Among the primary food plants, *T. tomentosa* and *T. arjuna* are rich in moisture, nitrogen, protein, minerals, sugar, glycoside, starch, tannin and volatile compounds, while *L. indica* and *T. paniculata* have a low percentage of fibre along with a high percentage of sugar, starch and minerals (Table 20). This may account for the better yield of cocoons on these four plants. On the other hand, *S. robusta* leaves contain a high percentage of fibre and a lower mineral, sugar and moisture content, which may be responsible for the higher larval mortality in the advanced stages.

14.2 Haemolymph composition

Hydrogen ion concentration: The pH of haemolymph is slightly acidic (6.6) but attains neutrality at each moult. There is no change in pH in the larval instars, in the pupae and in the adults. In diseased larvae the pH of the body fluid increases toward alkalinity.

Inorganic constituents: The ionic composition of *A. mylitta* haemolymph (19) is low in Na and higher in K, Ca and Mg (Table 21). The concentration of K is very high compared to that in *Bombyx mori* (24 to 32%).

Table 20 — Foliar constituents of primary food plants of tropical tasar (percentage on oven dry basis)

Food plants	Moisture	Total N	Crude protein	Crude fibre	Total minerals	Reducing Sugar	Total sugar	Starch	Crude lipid	Crude fat	Crude sterol	Glycoside	Tannin	Volatile Compd.s
S. robusta	61.00	1.60	9.80	19.40	4.50	4.70	5.30	12.50	4.00	0.90	2.70	2.40	9.10	0.03
T. tomentosa	71.71	1.70	10.90	12.40	6.50	2.40	7.90	15.00	3.60	0.80	2.50	3.10	16.20	0.06
T. arjuna	73.96	1.70	10.50	7.70	7.10	4.30	5.70	11.10	4.50	1.30	2.90	2.70	19.60	0.11
L. indica	58.30	1.55	9.70	6.87	8.29	2.69	10.79	14.40	–	–	–	–	–	–
L. speciosa	71.30	1.79	11.17	20.28	5.51	3.00	6.18	11.19	–	–	–	–	–	–
T. paniculata	64.30	1.34	8.37	9.80	8.73	2.56	7.93	12.19	–	–	–	–	–	–
L. parviflora	73.00	2.14	13.39	11.07	6.05	1.51	5.47	10.03	–	–	–	–	–	–
C. arborea	72.30	1.32	8.27	15.48	4.77	1.18	6.08	9.74	–	–	–	–	–	–
Z. muritiana	64.60	2.46	15.37	15.76	6.67	1.87	7.57	16.83	–	–	–	–	–	–

Table 21. Ionic composition of *A. mylitta* haemolymph

Milliequivalent/litre					Percent of haemolymph			
Na	K	Ca	Mg	Sum of cations	Na	K	Ca	Mg
1.3	49.7	21.9	37.7	110.6	1.2	44.9	19.8	34.1

Table 22. Carbohydrate levels in the food plant leaves, haemolymph and excreta of *A. mylitta* during postembryonic development

(Milligrams per gram)

Larval instars	Food plant			Haemolymph		Excreta	
	Type	Reducing sugar	Total sugar	Reducing sugar	Total sugar	Reducing sugar	Total sugar
I	Tender	2.100	8.120	0.325	1.900	2.012	4.350
		3.570	9.470	0.450	3.321	1.600	2.850
II							
III	Medium			0.575	4.187	0.687	2.775
IV		3.910	10.480	0.650	5.133	0.662	2.000
	Mature						
V				1.425	6.018	0.552	1.650

Carbohydrates: Reducing and total sugars increase in the haemolymph (154) and decrease in the excreta with the advance of larval age (Table 22). The difference between the total sugar in the food plant and the excreta indicates that a major part of the sugar is utilized for survival, growth and glycogen deposits (156).

The reducing sugars, utilized mostly in the form of nucleotides and nucleic acids, play a central role in glycolysis. Most of them are rapidly converted into nonreducing sugars, which accounts for the lesser quantity of reducing sugars in the excreta.

Amino acids

Amino acids in tasar food plants, eggs, larvae and pupae: The nineteen free amino acids (F.A.A.) commonly found in eggs, larvae, pupae and in the food plants sal, asan and arjun are cysteic acid, aspartic acid, glutamic acid, serine, glycine, lysine, asparagine, threonine, histidine, glutamine, proline, α-alanine, β-alanine, tyrosine, valine, leucine/isoleucine, arginine, cystine and methionine sulphoxide. Food plants have seven more amino acids: methionine, phosphoserine, α-amino adipic acid, hydroxyproline, phenylalanine, thyroxine and taurine.

Protein-bound amino acids: Fifteen of the nineteen free amino acids are present in protein form in the haemolymph. A striking feature is the absence of β-alanine, glutamine, asparagine and arginine in haemolymph proteins and their presence in free state. The other four — hydroxyproline, phenylalanine, thyroxine and methionine — are present in the haemolymph protein but absent in free state. This indicates that tasar silkworms are unable to produce these four amino acids despite their availability in the leaves of the food plants.

Amino acid changes in the haemolymph of diseased larvae — Whereas all nineteen of the free amino acids are present in the healthy larva, the virus-infected larva is deficient in threonine, tyrosine, valine, leucine/isoleucine and glutamine, and the bacteria — and microsporidia-infected larva lacks only glutamine (1).

Table 23. Free amino acids in *A. mylitta* larvae with an interchange of food plants

	(+ present, ++ abundant + – trace)							
	VI instar					V instar		
Amino acids	I–IV sal	I–IV asan	I–III Sal IV asan	I–III asan IV sal	I–V sal	I–V asan	I–IV sal V asan	I–IV asan V sal
–alanine	+	++	++	++	++	++	++	++
Proline	+	++	++	+	+	++	++	+
Tyrosine	+	++	++	++	+	++	++	++
Threonine	+–	+	+	+	+	++	++	++
Valine	+–	++	++	++	+	++	++	++
Leucine/ isoleucine	+–	+	+	+	+–	++	+	+
Asparagine	+	++	++	++	+	++	++	+

Interchange of food plants: The incidence of diseases is noticeably higher in larvae reared throughout on sal than in larvae reared entirely on asan. The interchange of food plants, however, has been shown to improve the larval survival rate. Table 23 shows the relative presence of certain free amino acids in the fourth and fifth instars reared with an interchange of food plants in the earlier instars.

Nitrogenous wastes: Whenever the amino acid pool in the haemolymph is disproportionate to the actual demand for free amino acids, the excess is passed out in the excreta, as retention would be fatal. Analysis of tasar silkworm excreta indicates that the percentage of nitrogenous wastes increase from the third through fifth instars. In the adult's urine ten free amino acids are present, while protein–bound amino acids are absent; conversely, in the larval excreta there are no free amino acids, while eleven protein–bound amino acids are present.

Composition of silk: The four types of silk produced in India differ significantly in colour, lustre and other physical properties. The amino acid composition of the fibroin and the sericin of each is given in Table 24, and the percentage of different elements in tasar and mulberry silks in Table 25.

As compared to mulberry silk, the fibroin of tasar silk is more resistant to acids and alkalies, less soluble in concentrated solutions of salts like $ZnCl_2$, $CaCl_2$, LiCl and cuprammonium solution and more resistant to the action of oxidizing agents (161).

Table 24. Comparative amino acid composition of tropical tasar silk fibroin and sericin (Amino acid N as percent of total N moisture free)

	Mulberry		Tasar		Muga		Eri	
Amino acids	Fibroin	Sericin	Fibroin	Sericin	Fibroin	Sericin	Fibroin	Sericin
Glycine	43.75	9.85	24.24	11.61	25.55	13.27	26.42	18.62
Alanine	29.05	3.21	39.00	4.67	34.34	1.57	35.35	2.09
Valine	1.85	2.20	0.67	4.18	0.53	2.46	0.54	0.82
Leucine	0.42	1.12	0.35	2.00	0.40	0.60	0.38	1.24
Isoleucine	0.53	0.67	0.36	1.07	0.39	0.55	0.52	0.60
Serine	10.00	19.31	8.62	9.86	7.88	15.48	4.96	7.15
Threonine	0.90	5.90	0.32	8.84	0.80	9.48	0.36	2.60
Aspartic acid	1.51	10.30	5.53	8.11	4.82	9.78	3.25	6.77
Glutamic acid	1.07	2.34	0.78	5.50	1.17	4.56	0.66	3.88
Phenylalanine	0.50	0.27	0.42	1.56	0.56	—	0.64	0.49
Tyrosine	0.42	1.51	4.71	5.40	4.61	4.75	5.37	4.34
Lysine	0.60	26.83	0.05	26.38	0.29	20.51	0.30	26.27
Histidine	0.36	5.97	1.68	5.05	1.06	2.81	1.53	3.86
Arginine	1.90	1.21	11.84	5.47	12.25	3.38	6.95	14.19
Proline	0.50	0.02	0.70	0.60	0.47	0.30	0.52	0.20
Tryptophan	0.39	0.24	2.04	0.43	2.80	0.19	0.39	0.16
Cystine	0.08	0.01	0.29	0.03	—	0.08	—	—

Table 25. Chemical composition of tasar and mulberry raw silk

	Percent	
Elements	Tasar	Mulberry
Carbon	47.18	47.78
Hydrogen	6.30	6.23
Nitrogen	16.85	18.90
Oxygen	29.67	26.04

Enzymes

Digestive enzyme: Six enzymes — amylase, inulinase, maltase, lactase, raffinase and glycogenase — are present in different regions of tasar silkworm's alimentary canal.

Proteolytic enzyme: The proteolytic enzyme, which more or less resembles pancreatic enzyme trypsin, is secreted by the galeae of the moths as a fluid called cocoonase. Another secretion from the labial glands acts as a buffering agent for the cocoonase. An apparatus designed for the collection of cooonase in liquid state is shown in Figure 81.

When the adult attempts to escape from the cocoon, the cocoonase runs down the glass tube, from which it is collected. The fluid is clear, colourless and basic (pH 8.3–8.7), and solidifies at –10° C. A single moth discharges 0.2–0.6 ml. The cocoonase can also be collected in semicrystalline form from the surface of the galeae just before emergence. When dissolved in a buffer, the crystalline deposit shows impressive proteolytic activity, as high as that of the cocoonase. Between 200 and 250 micrograms of enzyme may be collected from each insect and preserved at –20° C. Disk-gel acrylamide electrophoresis has revealed (42) that enzyme thus collected from *A. mylitta* has exactly the same electrophoretic mobility as the cocoonase of *A. polyphemus*. The amino acid composition and the molecular weight of the cocoonase of those two species are compared in Table 26.

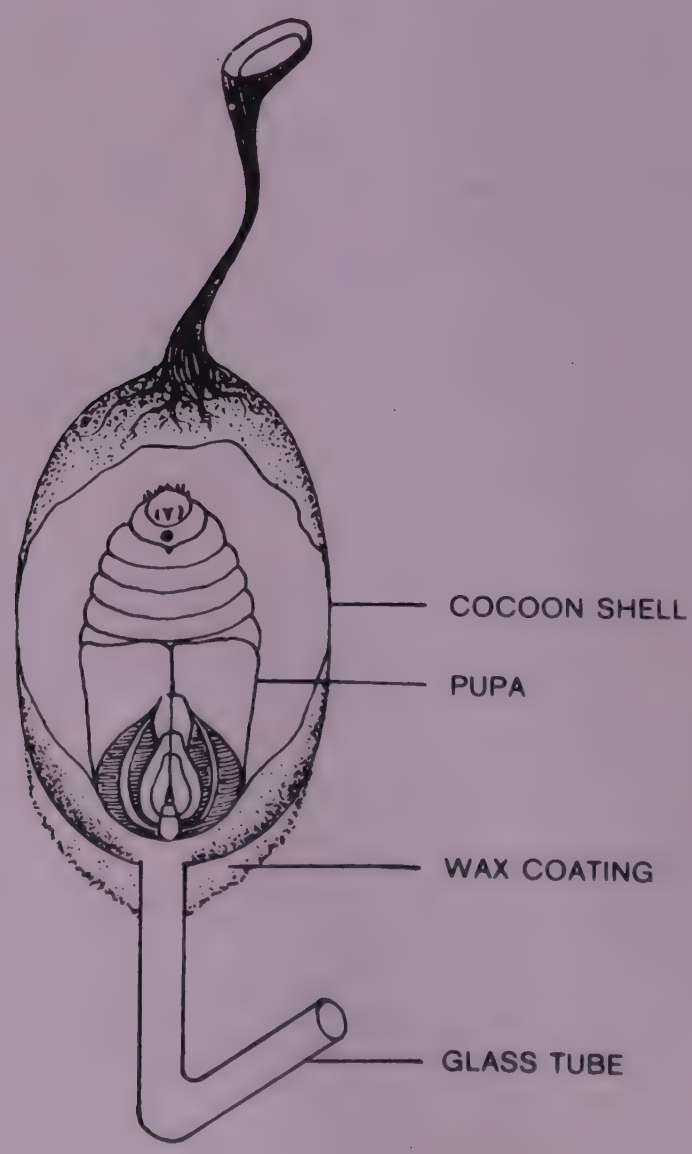


FIGURE 81. Apparatus for the collection of liquid cocoonase

Table 26. Amino acid composition and molecular weight of *A. mylitta* and *A. polyphemus* cocoonase

Amino acids	A. mylitta	A. polyphemus
Aspartic acid	24	24
Threonine	17	18
Serine	21	19
Glutamic acid	15	13
Proline	10	9
Glycine	27	30
Alanine	18	17
Cysteine	6	6
Valine	17	18
Methionine	3	2
Isoleucine	14	10
Leucine	15	15
Tyrosine	8	8
Phenylalanine	3	4
Lysine	15	12
Histidine	4	3
Arginine	7	9
Tryptophan	2	2
Molecular weight	23 991	23 146

Lipid metabolism – The lipid and fat contents during the different stages of A. mylitta development are shown in Figure 82.

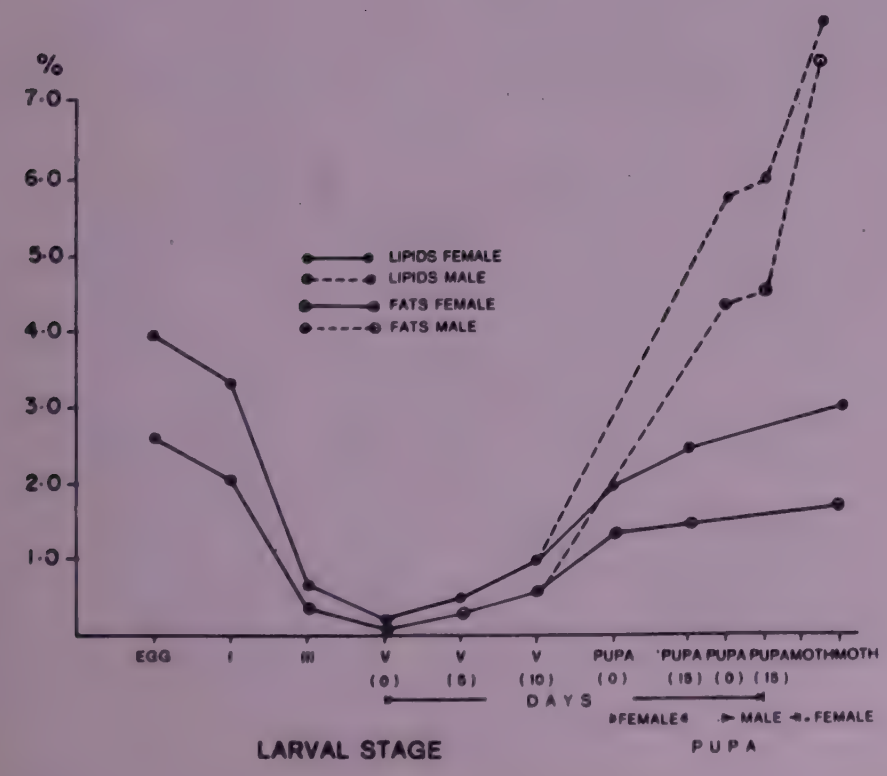


FIGURE 82. Variation in the lipid and fat contents of *A. mylitta* at different stages of development

14.3 Sex attractant

A simple apparatus (Figure 83) has been devised for collecting sex pheromone from the virgin females of pests at -30°C by passing dry air over virgin female moths. It can be utilized as a trap to attract the counterparts of different pests (79).

14.4. Pigments

Four phenolic pigments: Dopa, Dopamine, catechol and protocatechuic acid — are present in the eggs, and the integument of the green larva contains β-carotene, cholesterol, a sugar galactose and nineteen amino acids. The pigments in green pupal haemolymph occur not in the free state but as chromoproteins which yield β-carotene on hydrolysis.

The presence of carotenoid — and flavonoid-like pigments has been detected in primary food plants. Three carotenoids — β-carotene, canthaxanthin and cryptaxanthin — are common in cocoons harvested from sal, asan and arjun. In addition, sal cocoons contain zeaxanthin, lutein, lycopene and echinenone, whereas asan and arjun cocoons have lutein and violxanthin, respectively.

As for flavonoid pigments, the cocoons of sal and asan contain quercitrin and those of arjun isoquercitrin in the form of glycosides. Besides, catechin and epicatechin are present in sal cocoons and quercetin and rhamnetin in asan cocoons as free flavonoids. Arjun cocoons contain myricetin and quercetin.

14.5 Phytohormones

The injection of phytoecdysones extracted from a number of ferns of the genera *polypodium* and *podocarpus* into diapausing pupae of *S. cynthia*(141) and *A. pernyi*(200), terminated the pupal diapause in three weeks. Hormones extracted from *Polistichum accleatum, Pteris cretica* and *Cyatahula capitata* by the standard method (57) produced satisfactory results in A. mylitta (45–60%). Of the five authentic phytoecdysones tried, only cyasterone proved to be highly effective in inducing pupal diapause (Chapter 7).

14.6 By-products

The dead pupae which remain after reeling are very rich in protein (63–65%), oil (20–25%), carbohydrates (10%) and minerals (7–8%). After extracting the pupae oil, which can be used as an ingredient in soap because of its good cleansing power, the remaining powder has a high nutritive value (80% protein) and may be used in the baking industry for the preparation of protein-rich biscuits (2).

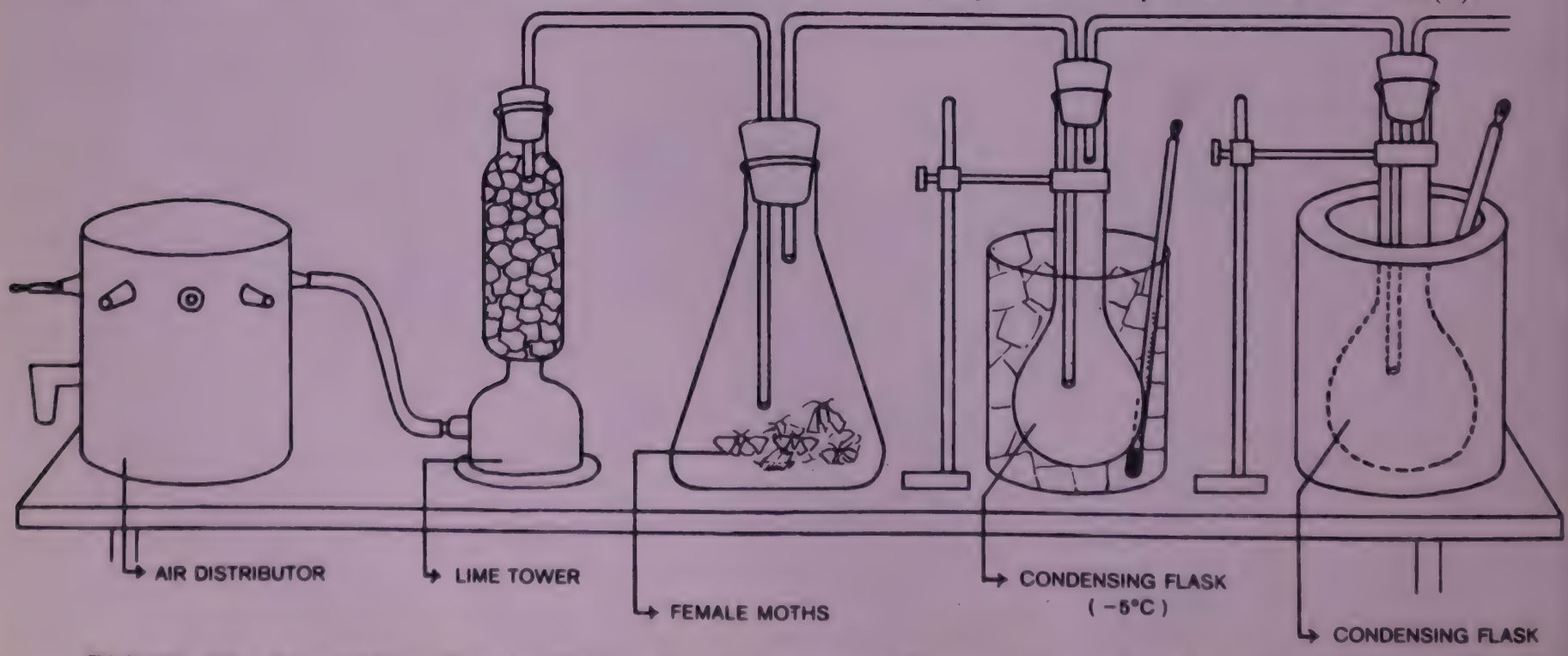


FIGURE 83. Apparatus for isolating sex pheromone from virgin female pests

Chapter 15

SILK REELING AND SPINNING

The filament of tropical and temperate tasar is continuous and reelable as the cocoons are of the closed type. The reeling and spinning of these two silk varieties, being quite comparable, are thus described together in the present chapter.

15.1 Sorting

The traditional method of sorting simply eliminates flimsy, stained and pierced cocoons. As cocoon colour, size and compactness have a significant influence on reeling performance, sorting on those lines helps ensure uniform cooking and reeling for the production of quality raw silk.

Normally the cocoons of *A. mylitta* (Daba) are either yellow or grey with different grades of compactness. The cocoons can be graded into large, medium and small according to the size ranges in Table 27.

The influence of size and colour on reeling performance is shown in Table 28.

There is no noteworthy colour variation in *A. proylei* cocoons, but sorting by size is nonetheless desirable.

Table 27. Size grading of Daba reeling cocoons

Size	Long axis (cm)	Short axis (cm)
Large	5.60–5.76	3.35–3.41
Medium	5.37–5.46	3.15–3.25
Small	4.86–4.96	2.84–2.91

Table 28. Influence of colour and size on reeling performance

Characteristics	Cocoon quality					
	Large		Medium		Small	
	Yellow	Grey	Yellow	Grey	Yellow	Grey
Av. filament length (m)	1 058	1 112	894	931	777	884
Av. filament denier	11.69	11.94	10.80	10.86	9.85	10.26
Av. length of raw silk reeled (4 ends) per hour (m)	6 983	6 578	6 763	5 641	7 400	6 939
Av. denier of raw silk	63.19	67.55	64.03	63.20	57.07	61.19

15.2 Stifling

The fresh cocoons are stifled not only to prevent moth emergence by killing the pupae but, also to ensure proper preservation of reeling cocoons by eliminating the moisture content (65%). The different methods of stifling are briefly described below.

Sun drying: Although sun drying is economical and widely practised owing to its simplicity, prolonged exposure to sun denatures the sericin, which makes the cooking of the cocoons difficult and thereby affects the reeling performance.

Steam stifling: Sun drying is necessary after steam stifling for proper preservation of the cocoons. The storage of semi-wet cocoons causes fungus attacks and vitiates reeling efficiency. Basket and chamber steaming are two common methods of steam stifling.

Basket steaming: This very crude method is widely used in small reeling establishments. One to two thousand cocoons are put into a bamboo or cane basket having tightly woven sides to check the steam outflow and a loosely woven bottom to let in the steam (Figure 84). The basket is wrapped with a thick, wet cloth to ensure effective steaming and placed over a water filled container which is heated by fire. The cocoons are steamed for 20 to 30 minutes.

Chamber steaming: This method is practised in large tasar reeling establishments. The steamer is a double-walled cylindrical chamber with a rectangular bottom for water, a small furnace and a pressure gauge. The cocoons are placed in a removable perforated cylinder (Figure 85). Smoke is exhausted through the space between the two walls and the "chimney". The cocoons are steamed for 20 to 30 minutes at 5–10 lb/in^2.

Hot-air drying: The hot-air oven or chamber has an electrical or fuel-operated heating source and a built-in air circulation mechanism for drying. The cocoons are spread on perforated shelves (Figure 86). At 80–90°C the pupae are stifled, and in 10 to 15 hours they are completely desiccated. If the quantity of cocoons to be stifled is large, partial (20 or 40%) desiccation may be effected to shorten the operation.

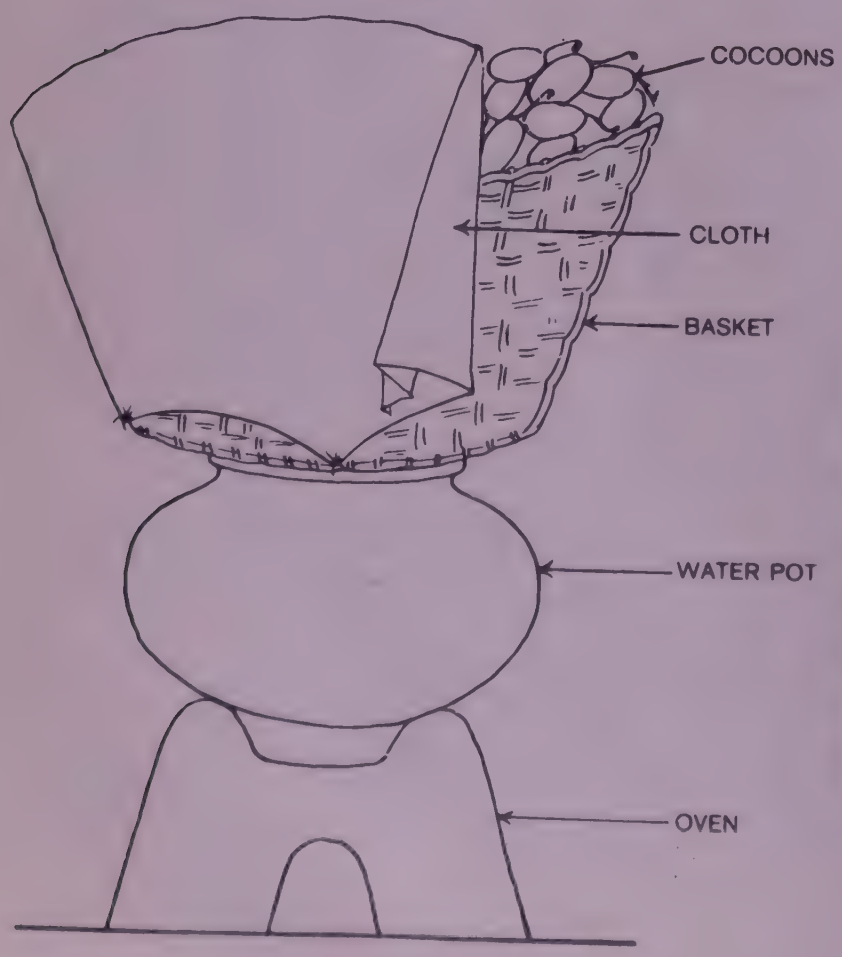


FIGURE 84. Basket steaming

FIGURE 85. Chamber steaming

FIGURE 86. Hot-air drying

FIGURE 87. Storage of stifled cocoons in a wire-mesh rack

This technique is superior to sundrying and steam stifling, not only because it has a limited effect on both the sericin and the fibroin, but, also, because the cocoons can be stored immediately.

15.3 Storage

Even fully dried cocoons are liable to mould damage during periods of high humidity. Reeling cocoons are ideally stored at 25–30°C and 60–65% R.H. The storage room must be rat and insect proofed, ventilated and periodically disinfected with formalin. The stifled cocoons should be thinly spread, preferably on wire–mesh racks (Figure 87).

15.4 Reeling

Reeling involves simultaneous unwinding of filaments from several cocoons, imparting twist and winding the composite raw silk thread onto a bobbin.

Cooking: Uniform softening of the hard cocoon shell by cooking is a vital operation as it makes possible smooth unwinding of the filament without frequent breakages, thereby improving producitivty and the raw silk quality. The technique depends on the nature and content of the sericin present.

Tasar cocoon is very hard and compact. Unlike the mulberry cocoon, it cannot satisfactorily be softened by boiling in plain water. The poor solubility of the sericin in water and alkaline/acidic solutions, due to the presence of tanning substances, makes the cooking and degumming of tasar cocoons difficult. Wet–basin reeling of tasar is not advantageous.

Traditional method: The cocoons are individually wrapped in silk waste, especially at the peduncle end, to prevent the shell from bursting (Figure 88), and are treated in a boiling alkaline media for 4 to 5 hours. This technique involves much labour and the reeling results are poor.

FIGURE 88. Traditional method of cooking cocoons

Improved technique: Enzymatic decomposition of the sericin at low temperature renders it soft enough for reeling. Solutions of cocoonase, papain, trypsin, pepsin and Biopril–50 have been tried; the last has been found to be the most efficient because it not only provides uniform softening but also reduces the cooking/steaming period. The slightly different applications of this technique with *A. mylitta* and *A. proylei* are described below.

*A. **mylitta:*** The cocoons are first boiled in plain water for 1 to 1½ minutes and then steamed at 15 lb/in^2 for 40 to 60 minutes, after which they are left in the chamber while the pressure is gradually released. The cocoons are then loosely wrapped in a porous cloth and soaked in 0.1–0.2% Biopril–50 solution for 20 to 22 hours, initially at 40–50°C and later at room temperature. After being spread out on an ash bed, the cocoons are semi–dried and then deflossed for dry–basin reeling. This method gives about 65% reelability with Daba and Bogai.

*A. **proylei:*** The technique is basically the same as that described for *A. mylitta* except that the cocoons are boiled and steamed for 1 hour and 30 minutes, respectively, and 0.025–0.50% Biopril–50 solution is used for soaking. This application of the technique gives up to 55% reelability.

The cooking procedures described above are for dry–basin reeling; however, because the filament of *A. proylei* is finer (5D) than that of *A. mylitta* and the shell is not very hard, they can be reeled like mulberry cocoons on a wet basin, but with slightly inferior results.

Deflossing: The cooked cocoons are deflossed until the filament end is found. Deflossing is carried out individually by hand, as collective brushing results in opening of the peduncle ends. Little time is required for the individual hand–brushing of tasar because the cocoon is large and the number consumed daily per reeler is very small.

Reeling operations: Normally, five or six deflossed cocoons of *A. mylitta* (Daba) or eight to ten *A. proylei* are fed into the reeler per end to produce, respectively, 60/65 denier or 40/45 denier thread. The filaments are passed together to the delivery roller, from which they pass to the bobbin through the final thread guide. Twisting and winding take place simultaneously by means of a ring and a traveller on the ring rail.

The formation of thread on the multiend reeling machine is different. The filaments are passed together through a jette–boute, and then the composite raw silk thread, travelling through the thread guides, is finally wound, without twist, on the wooden reels.

Reeling appliances — Natwa: This applicance is a hand swift made of bamboo and wood (Figure 89). The reeler, sitting cross-legged, reels a number of filaments and winds them on the natwa after imparting twist to the composite yarn by hand. This is such a slow process that a reeler can only reel about 80 cocoons in eight hours; however, because it ensures better control of the individual cocoon filaments, the resulting yarn is of good quality. Despite low productivity, it is widely used because of its simplicity and small investment cost.

Trivedi reeling machine: This pedal-driven machine has four spindles with a vertical traverse mechanism for distributing the reeled thread uniformly on the bobbin. The average daily production of raw silk is 180 to 200 g (Figure 90).

CTRS reeling machine: Designed on the spinning principle, the CTRS reeling machine, also pedal driven and four spindled, has a wooden swift (50 cm in circumference) for delivering the composite silk yarn to the fast-rotating bobbin fixed on the spindles. There is a small step-pulley on the spindle driving shaft for changing the spindle speed when necessary. The wooden swift, besides increasing the delivery rate, also reduces lapping by lessening the contact of the raw silk thread with the wood surface (101). All the working points are fitted with ball bearings for very smooth operation. The machine is also equipped with various other devices which help increase its efficiency (Figure 91).

The average reeling efficiency of this machine with raw silk from Daba cocoons is illustrated by the following data:

Length reeled per h/4 ends	7 200 m
Denier of yarn	62.41D
Production by weight/h/4 ends	50 g (400 g/day)
Reelability	65.6%

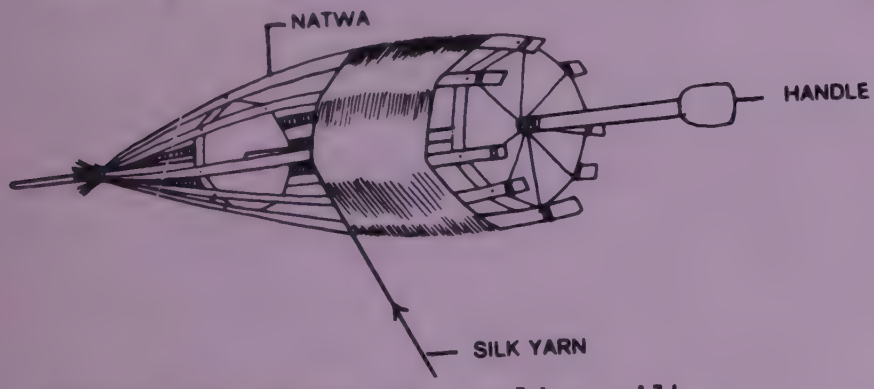


FIGURE 89. Natwa for reeling silk yarn

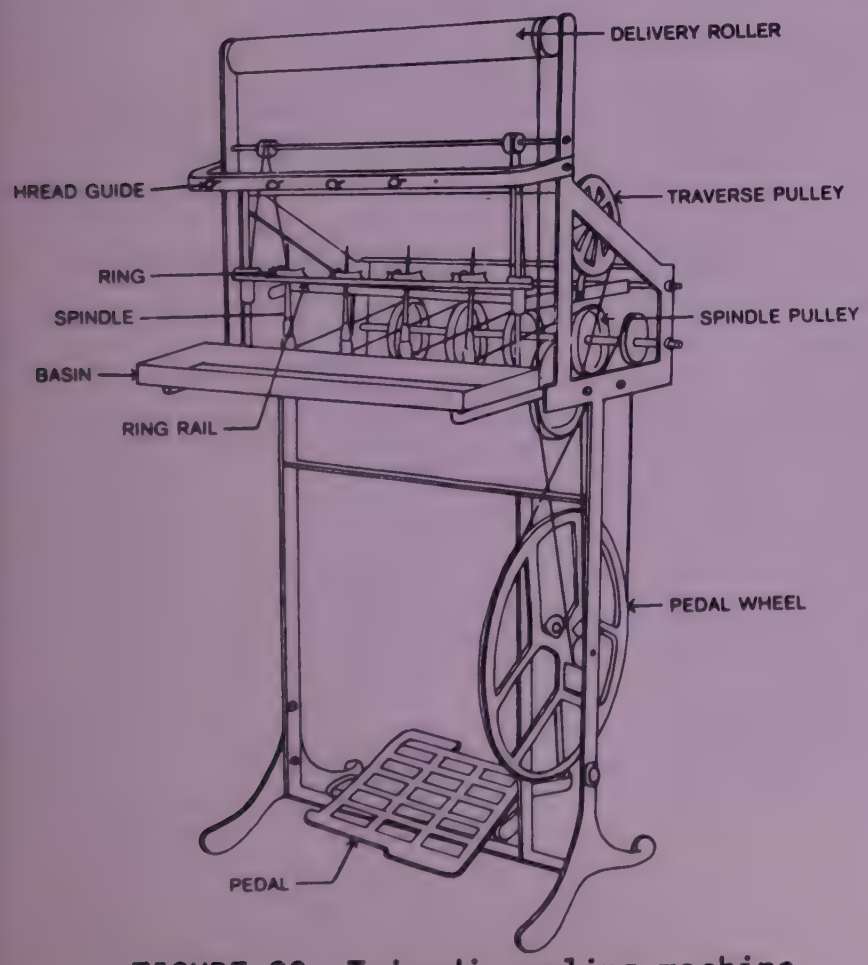


FIGURE 90. Trivedi reeling machine

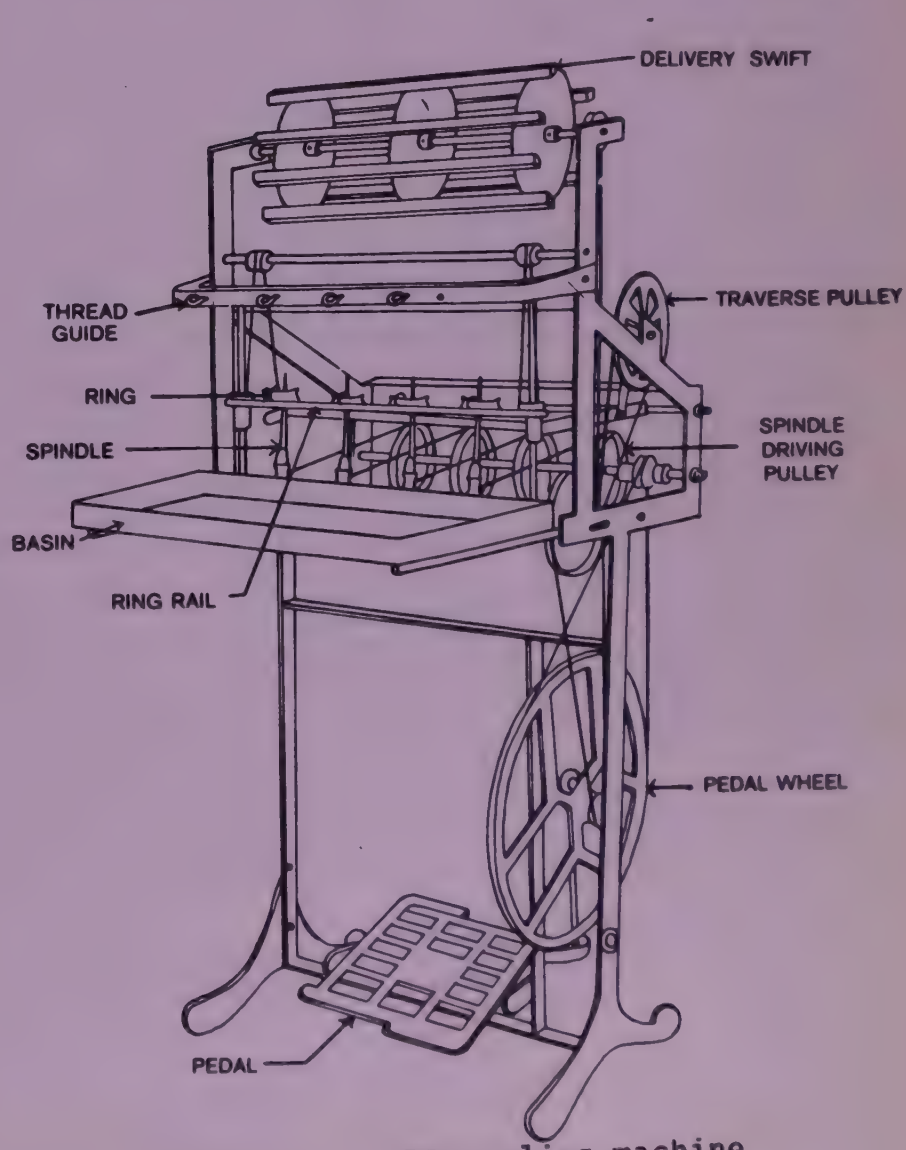


FIGURE 91. CTRS reeling machine

Modified CTRS multiend reeling machine: Tasar cocoons, especially *A. proylei* can also be reeled on a dry basin with a multiend machine, such as the cottage type of four-end reeling machine with jette–boute (without croissure) and button (Figure 92).

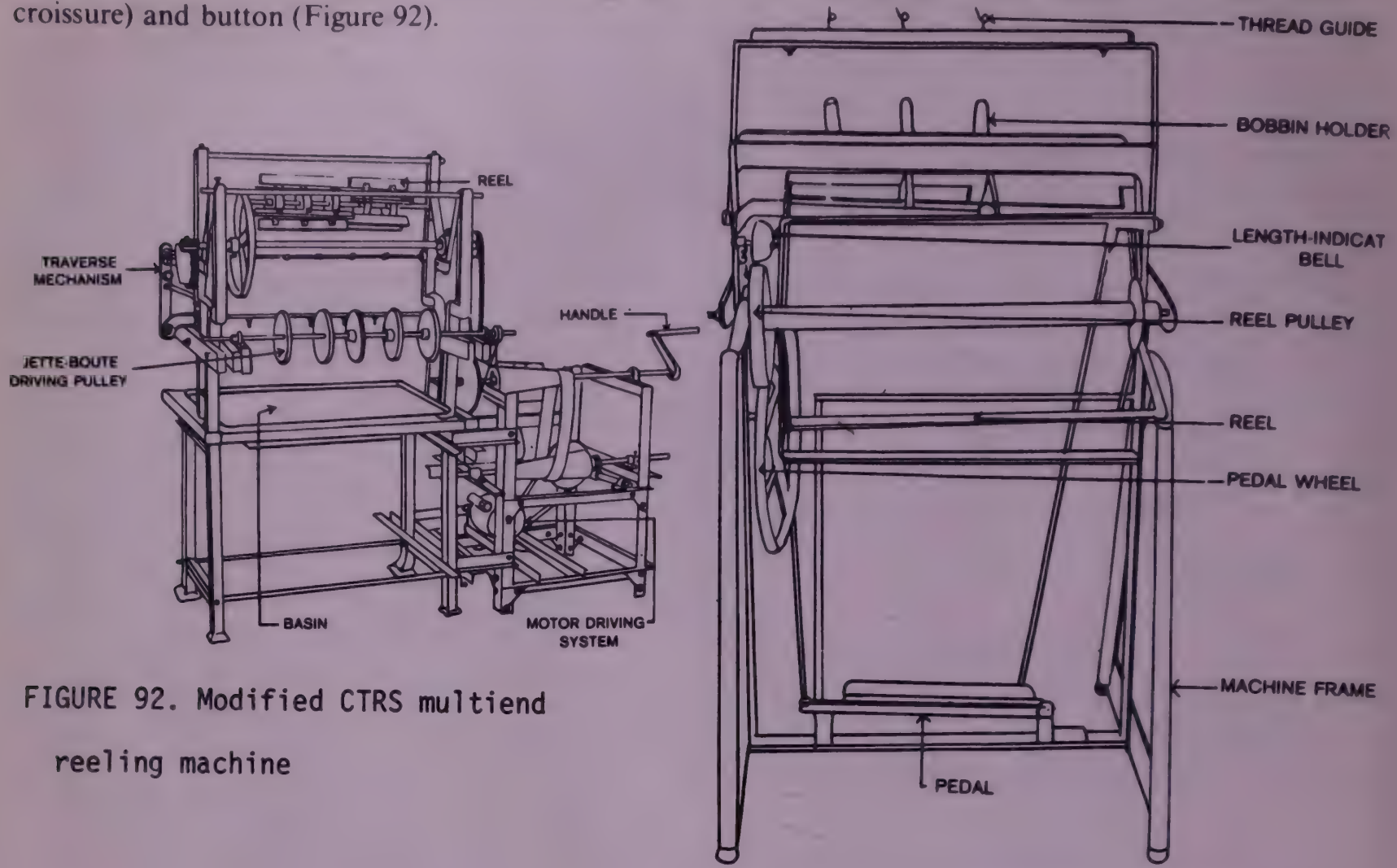


FIGURE 92. Modified CTRS multiend reeling machine

FIGURE 93. Foot-operated re-reeling machine

The average output of the CTRS reeling machine and the modified CTRS multiend reeling machine with *A. proylei* cocoons soaked in Biopril–50 are compared in Table 29.

Foot-operated re-reeling machine: This simple, economical machine is suitable for small units. Although one person can operate four ends at a time (Figure 93), it has an ordinary yarn distributing system and the production capacity is very low.

Table 29. Comparative average output of the CTRS and the modified CTRS multiend reeling machines

Raw silk output	CTRS reeling machine	CTRS modified multiend machine
Length reeled per h/4 ends (m)	5 470	9 780
Denier	35.27	24.92
Production by weight per h/4 ends (g)	22.0	27.5
Reelability (%)	51.0	52.0

Re-reeling

After reeling the raw silk from bobbins or reels is rewound onto standard–sized reels about 150 cm in circumference.

Motor-driven standard re-reeling machine

This two–sided machine is widely used in large reeling operations. One operator can attend to about 15 ends. It has an improved traverse distributor system that forms diamonds in the hank (Figure 94).

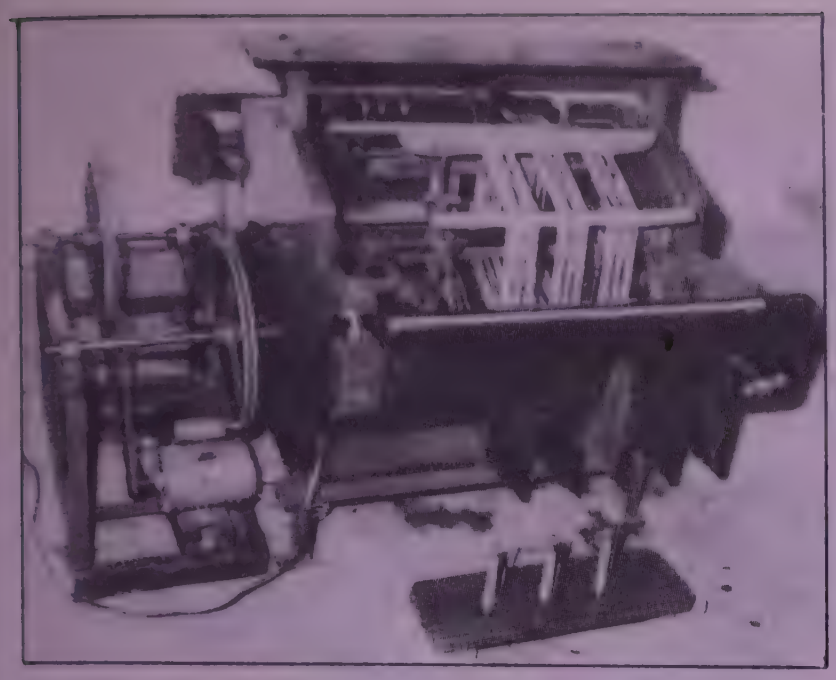


FIGURE 94. Motor-driven standard

FIGURE 95. Preparation of ghicha yarn

The traverse mechanism consists of adjustable gears. For instance, with a gear ratio of 10:18, for every 18 revolutions of the reel the traverse eccentric disk makes 10 revolutions, thus moving the traverse bar forward and backward 10 times to produce 10 webs across the face of the hank. This pattern can be changed by altering the combination of gears.

Each silk hank formed on the re–reeling machine is 150 cm in circumference and weights 50 to 70 g for local transactions. The hank is twisted to form a skein, and a number of skeins are press–packed to form a "book" or bundle for commercial use.

15.5. Spinning

The filament from a cocoon is at most 60 to 70% reelable; however, the remainder can be spun. Pierced and otherwise defective cocoons and those which have been spoiled by improper cooking or reeling are also utilized for spinning. Spun yarn is coarser and more irregular in size than reeled yarn.

Silk waste: Unreelable silk that is utilized for spinning falls into the following categories:

Cocoon waste: Cocoons pierced by the emerging moths are the best quality waste. Discarded cocoons which are unreelable because of certain defects (insect infestation thin ends, doubles, etc.) can nevertheless be used for spinning.

Reeling waste: Reeling waste, which consitutes the major protion of total waste, includes cooking and brushing waste, as well as that obtained during reeling on account of cocoon feeding and end breakages or as basin residue (innermost shell layer). Like cocoon waste, it can readily be spun by hand or on a charkha.

Thread waste: This consists of all bits of yarn obtained during knotting and cleaning in the various stages of commercial silk yarn production: re–reeling, winding, throwing and weaving. It is mechanically processed in the spinning operation.

Spinning yarns

Ghicha: Cooked tasar cocoons which are unreelable owing to opening of the peduncle end or a hard shell are used to produce the hand–drawn coarse yarn called ghicha. The spinner holds the cocoon in the left hand and draws out the entangled filament with the right hand, imparting a few twists by rubbing the yarn on the surface of an inverted pitcher (Figure 95). The spun yarn, subsequently made into hanks, is used only for weft because of its softness.

Katia: A lump of degummed and opened tasar reeling waste is drafted by hand. Twist is given to the strand by rotating the spindle on the indigenous "takli". The yarn is subsequently wound on the spindle.

Jhuri: The kind of yarn known as jhuri is spun from uncleaned and unopened tasar.

Spinning methods

Trivedi spinning wheel: This spinning wheel has a pedal–rotated flywheel, which directly drives the flyer and spindle. The opened tasar waste is held in the spinner's left hand and is drafted and fed to the wooden bobbin with the right hand, while the flyer simultaneously twists and winds the yarn (Figure 96). As this is a continuous spinning process, it can produce finer quality yarn.

This machine has been further improved by the incorporation of a traverse mechanism to wind the yarn over the entire length of the bobbin.

Chowdhury spinning wheel: This very simple spinning device is based on the ring spinning principle. All the parts except the spindle unit are wooden. The horizontally fitted spindle is provided with a ring and a traveller. The spinner shifts the ring occasionally to distribute the coils over the lengthof the bobbin (Figure 97). Still finer yarn can be spun on this wheel than on the Trivedi version. About 100 to 125 g of 20s (metric cotton count) of yarn can be spun from opened tasar waste in 8 hours. Production on the Chowdhury and Trivedi spinning wheels is comparable.

15.6 Physical and chemcial properties of the fibre

A. mylitta silk ranges from light to dark brown, whereas *A. proylei* silk does not show much variation in shade and is more lustrous. The tasar filament consists of two separate brins which are held together by sericin. Fibroin constitutes about 75 to 80% of the content, and the remainder is mostly sericin. *A. mylitta* and *A. proylei* silks are not very reactive to chemical reagents (120) and consequently present difficulties in bleaching and dyeing.

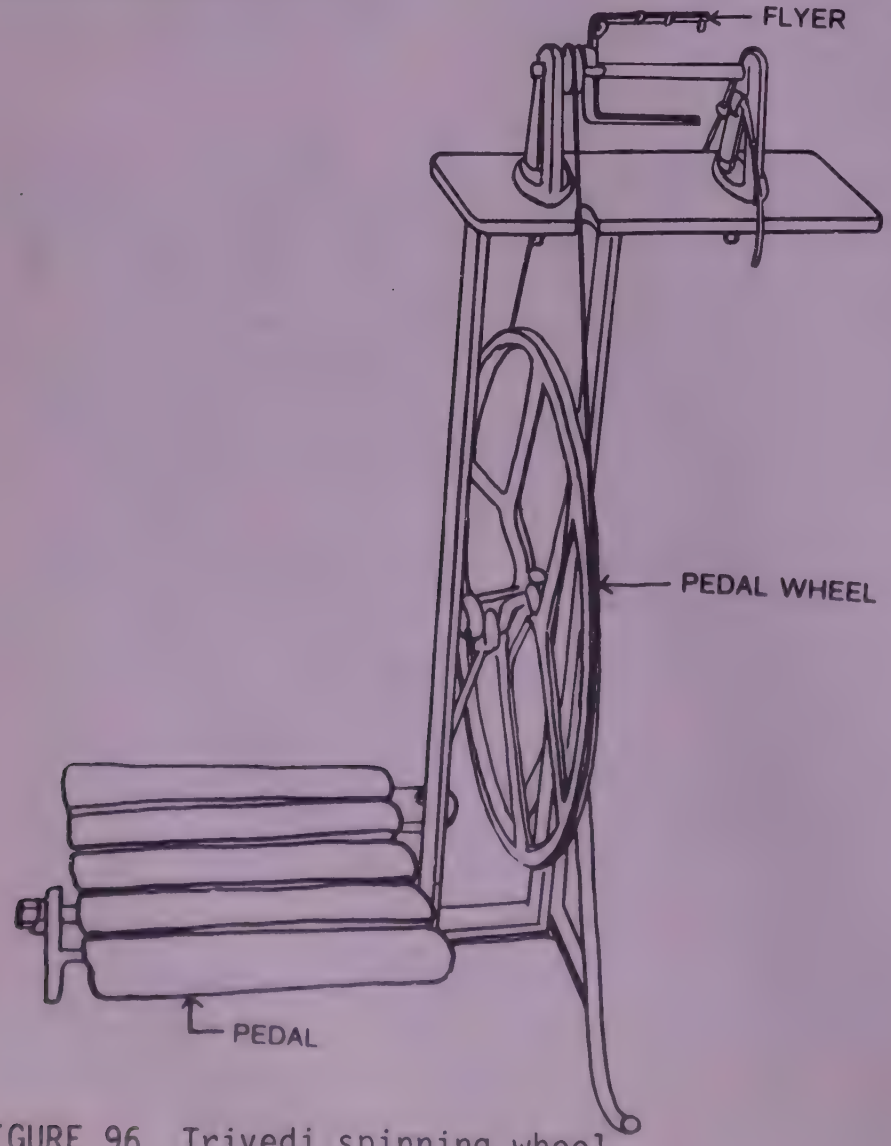


FIGURE 96. Trivedi spinning wheel

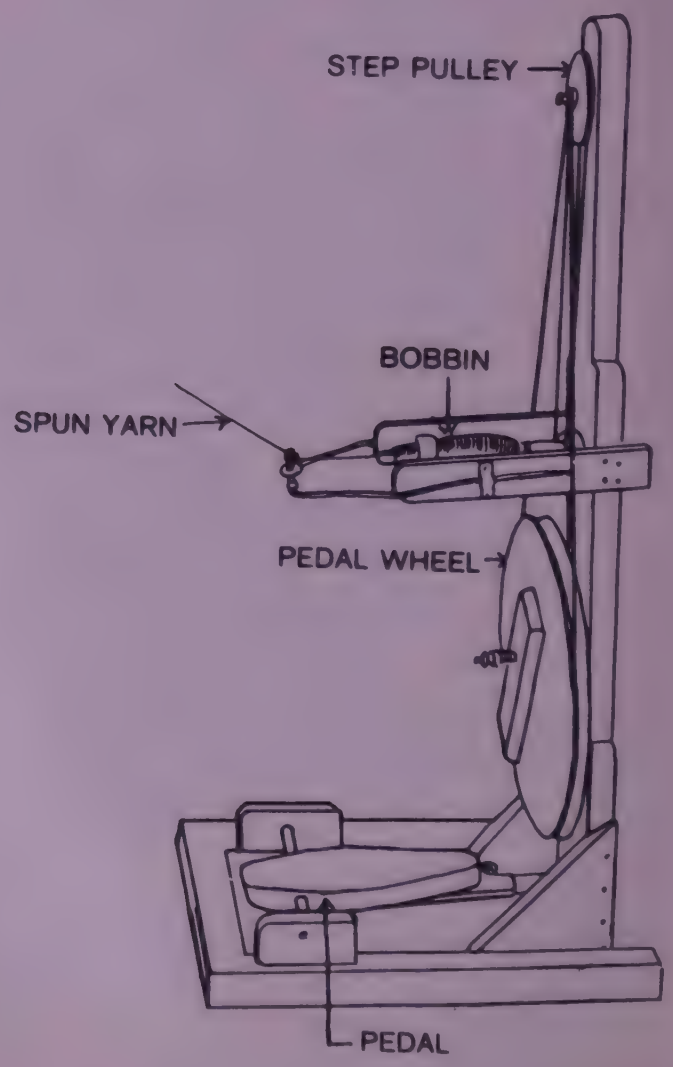


FIGURE 97. Chowdhury spinning wheel

Filament length: Filament length varies not only between the different races of *A. mylitta* but also within the same race. Daba cocoons yield about 800 m, whereas Raily, Modal and Modia, for example, yield 1 200 to 1 400 m. *A. proylei* cocoons contain 650 to 750 m of filament.

A simple apparatus known as an epprouvette is used for reeling single filaments from a cocoon (Figure 98).

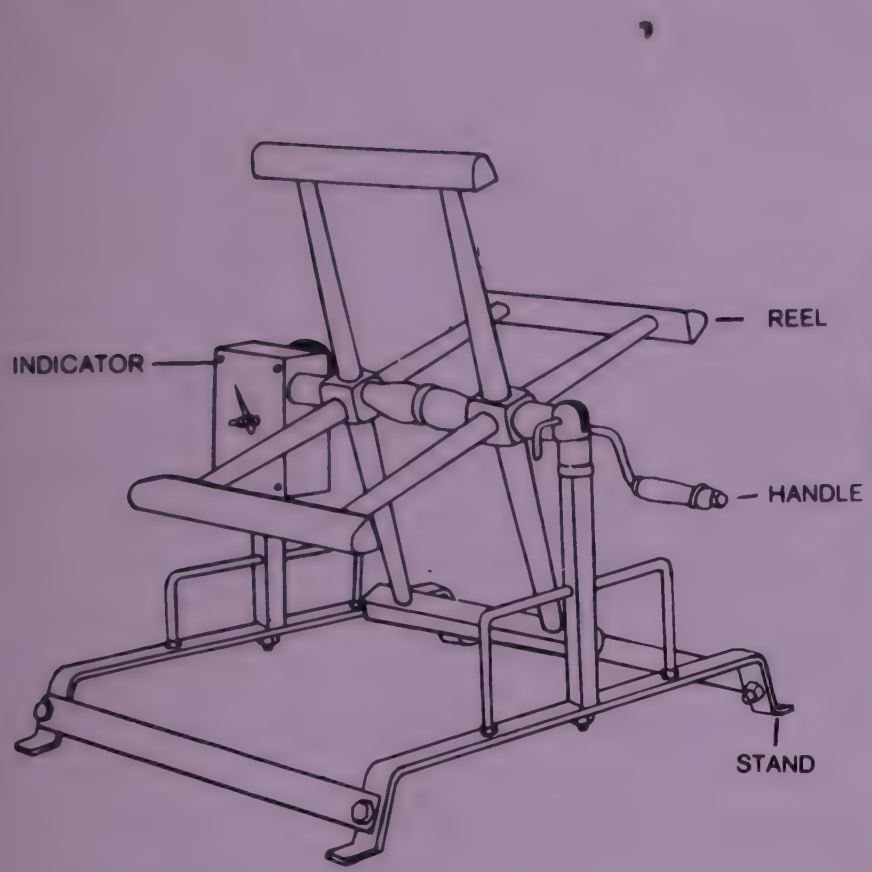


FIGURE 98. Epprouvette

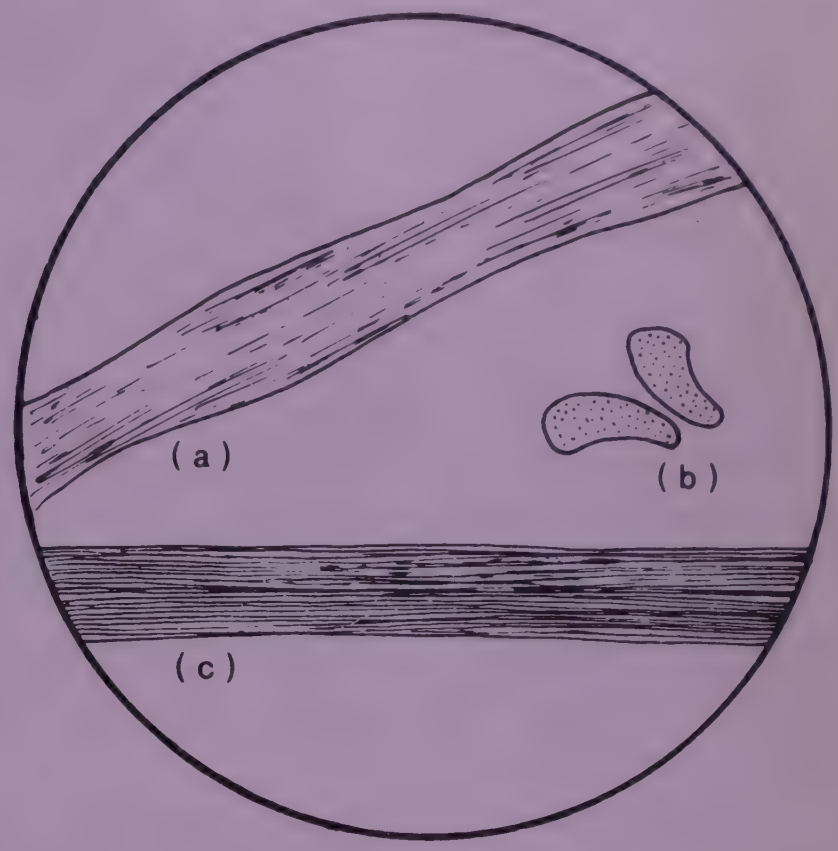


FIGURE 99. (a) Longitudinal view and (b) cross section of *A. mylitta* fibre; (c) longitudinal view of *A. proylei* fibre

Filament size: The size, or thickness, of the filament is measured in deniers — that is, the weight in grams of 9 000 m of filament.

$$\text{Denier} = \frac{\text{Weight of silk (g)}}{\text{Length of silk (m)}} \times 9000$$

The denier weight for the different ecotypes of *A. mylitta* ranges from 8–13, whereas for *A. proylei* it is about 5. The denier is not uniform throughout the reelable length because the peripheral layers consist of coarser filament.

Microscopy of tasar silk fibre

Longitudinal view: Tasar silk is comparatively broader than mulberry silk and has longitudinal striations representing minute fialments called fibrils.

In *A. proylei* the straitions appear continuously parallel to the long axis of the fibre; in *A. mylitta* they are discontinuous, appearing at more or less regular intervals. Furthermore, in *A. mylitta* unilke *A. proylei* portions of the filament are flattened, probably as a result of overlapping of fibres before the substance is hardened (Figure 99).

Cross-sectional view: Tasar fibre appears in cross-sectional view as an elongated triangle with rounded corners. The two facing sides of the triangle are covered by silk glue.

Hygroscopic nature: Tasar silk is highly hygroscopic and can absorb moisture up to 30% of its weight. It is therefore necessary to determine the amount of moisture in the silk lot at the time of sale. The officially allowed "regain" is 11%.

The conditioned, or mercantile, weight of raw silk can be determined with the following formula, in which D is the oven-dry weight.

$$\text{Conditioned weight} = D + \frac{D \times 11}{100}$$

X-ray view: Tasar fibroin is made of invisible crystals which perfectly reflect x-rays in definite direction. Moreover, their diffraction pattern has revealed the dominant presence of poly-∝—alanine. The infrared absorption spectrum of the regenerated fibroin film shows ∝— helix of poly-∝— alanine on untreated samples. When the film is treated with methanol, the spectrum changes to β-coils of poly-∝-alanine. It therefore follows that the main constituent of *A. mylitta* filbroin in the crystalline region is poly-∝-alanine, similar to that of *A. pernyi, A. yamamai, P. cynthia* and *P. ricini.*

Density: Density is an important consideration when blending silk with other natural or synthetic fibres (124). Tasar silk in raw state has a density of about 1.34. It is less dense than cotton, linen and rayon and very close to wool.

Electrical properties: Tasar silk, being a poor conductor, accumulates static electricity if subjected to friction. The static charge can be neutralized by increasing the conductivity of the material with water vapour and an antistatic finish. Owing to its insulating property, tasar silk can also be used for covering electric wires.

Tensile properties: The tenacity and elongation of *A. mylitta* silk are 1.8–2.2 g/d and 20–25%. With similar cooking conditions the tenacity of oak tasar is higher (2.5–2.8 g/d). Tensile properties vary in different layers of a cocoon. Tenacity increases from external to internal layers, and elongation increases inversely. Like wool, it loses strength by about 20% when wet.

Effect of heat: Tasar silk can be heated to 140°C without danger of decomposition. At 170°C it disintegrates rapidly, liberating an empyreumatic odour.

Action of alkalies: Tasar silk is not sensitive to dilute alkalies, though the lustre of the fibre is somewhat affected. Prolonged action of concentrated NaOH even in cold conditions dissolves the fibroin. Boil NaOH (1%) solution dissolves tasar silk in 30 to 50 minutes.

Action of acids: Tasar silk dissolves very slowly in cold concentrated HCL. Prolonged treatment in HCL or H_2SO_4 makes the fibre brittle. Organic acids like HCOOH and HOOC-CH(OH)-CH(OH)-COOH harden the sericin.

Part-III

TEMPERATE TASAR

The hybrid has already undergone over twenty successful generations without registering any noteworthy deterioration and has become established as a population. In view of this, the provisional nomenclature for the hybrid population, *A. proylei* Jolly, could be confirmed as a distinct species (99). The production of temperate tasar silk (*A. pernyi*) in China dates to the Han and Wei dynasties. The culture is largely confined to the northeast provinces (Liaoning, Shantung, etc.). The silk is utilized for the manufacture of the famous Chinese shantung and pongee. Three or four decades ago *A. pernyi* was introduced to Korea, Japan, the U.S.S.R. and other countries, but could not be established for various reasons. In Japan *A. yamamai* is being reared only on an experimental scale.

The extensive survey of the sub–Himalayan belt of India conducted in 1966 by the Central Tasar Research Station, Ranchi (Bihar), brought to light the vast wealth of oak in the region (74). The oak tract extends from Jammu and Kashmir in the west to Manipur in the east, embracing Himachal Pradesh, Uttar Pradesh, West Bengal, Sikkim, Assam, Arunachal Pradesh, Meghalaya, Mizoram and Nagaland. The main hindrance for non–mulberry silk cultures was overcome by the successful hybridization of the uneconomical indigenous *A. roylei* with its Chinese counterpart, *A. pernyi.* The resulting hybrid, *A. proylei* Jolly, proved to excel both parents in all economic characters and thus gave rise to temperate tasar culture in India. This industry has progressed rapidly, particularly in the northeastern states owing to ideal socioeconomic and rearing conditions.

Chapter 16

MORPHOLOGY

The five temperate tasar species: *A. proylei* Jolly, *A. roylei* Moore, *A. pernyi* Guerin-Meneville, *A. yamamai* Guerin-Menville and *A. polyphemus* Cramer — have the basic morphological characteristics of the Antheraea genus, as have already been described for *A. mylitta* D. (see Chapter 4); thus only those features which differentiate them are elaborated in Table 30.

Table 30 — Distinctive morphological characteristics of temperate tasar silk worms

Species Characteristics	*A. proylei*	*A. roylei*	*A. pernyi*	*A. yamamai*	*A. polyphemus*
Egg					
Colour	Bluish green	Bluish green	Brownish	Pinkish or brownish	Whitish grey
Size (mm)	2.8 x 2.2	2.5 x 2.0	2.5 x 2.0	2.8 x 2.4	2.8 x 2.4
Weight (mg)	8.0	7.0	7.0	8.0	8.0
Streak	Absent	Absent	Absent	Absent	Single (incomplete)
Follicular imprints	Oval (Fig. 100)	Polygonal (Fig. 77a)	Oval (Fig. 77e)	Irregular (Fig. 77g)	Polygonal (Fig. 77f)
Larva					
Newly hatched:					
Body colour	Black	Black	Dull black	Yellowish green	Straw
Head colour	Red	Brown	Orange	Red	Reddish brown
Larval size (mm)	6.5 x 1.0	6.0 x 1.0	6.0 x 1.0	7.0 x 1.0	7.0 x 1.0
Larval wt. (mg)	6.5	6.0	6.0	7.0	7.0
Mature:					
Body colour	Green	Green	Apple green with white marks	Green	Green
Head colour	Dull brown with 10 dark brown spots (Fig. 101a)	Dark grey with 12 dark brown spots (Fig. 101b)	Brown with 10 black dots	Green, plain	Dull brown, plain
Larval size (cm)	8.5 x 2.0	8.0 x 1.8	8.0 x 1.8	8.5 x 2.0	9.0 x 2.2
Larval wt. (g)	15.0	12.0	12.0	16.0	20.0
Cocoon					
Structure	Single shelled, oval, hard, non-fibrous, reelable (Fig. 102a)	Double shelled- Inner shell: oval, soft, slightly fibrous, reelable Outer shell: roughly polygonal, soft, thin, unreelable (Fig. 102b)	Single shelled, oblong, soft, slightly fibrous reelable (Fig. 102c)	Single shelled, oblong, soft, slightly fibrous, reelable (Fig. 102d)	Single shelled, oblong, soft, slightly fibrous, reelable (Fig. 102e)
colour	Light brown	Inner: creamish Outer: light brown	Light brown	Greenish yellow	Greenish brown
size (cm)	4.5 x 2.5	4.0 x 2.0	4.0 x 2.0	4.5 x 2.3	3.5 x 2.0
weight (g)	6.22	5.30	5.28	6.00	4.68
peduncle	Weak and short with ring	Thin and short with ring	Thin and short with ring	Thin and short with ring	Thin and short without ring
shell wt (g)	0.76	0.50	0.60	0.80	0.42
shell ratio (%)	12.90	9.40	11.30	10.60	13.30
Filament:					
shade	Creamish	Creamish	Brownish	White with greenish tinge	
denier	750	468	411	500	
	5.0	5.0	5.0	5.5	
Pupa					
size (cm)	3.5 x 1.8	3.4 x 1.7	3.4 x 1.7	3.8 x 1.8	
weight (g)	5.46	4.80	4.68	5.20	4.26
Moth					
Body length (cm):					
male	3.5	3.5	3.5	3.5	3.0
female	4.0	4.0	4.0	4.0	3.5
Wing expanse (cm)					
male	14.0	14.0	14.0	14.0	13.0
female	16.0	16.0	16.0	16.0	15.0
Male wing:					
ground colour	Greenish grey (Fig. 103a)	Greenish grey (Fig. 103b)	Camel brown (Fig. 103c)	Brownish yellow (Fig. 103d)	Grey, brown (Fig. 103e)
antemedian line	Pink with white inner border; border absent in hind wing	Pink with white inner border	Reddish brown with faint white inner border	Pink	Dark brown with a pink inner and a red outer border

Table 30 (concluded)

oblique line	Pink with white inner border	Pink with white inner border	Reddish brown with faint white inner border	Pink	Brown
postmedian line	Pink with white outer border	Pink with white outer border	Reddish brown with white outer border	Dark brown with white outer border; border absent in hind wing	Brown with a black inner and a pink outer border; slightly wavy in hind wing
Female wing ground colour	Brownish grey (Fig. 104a)	Dull brown (Fig. 104b)	Like male (Fig. 104c)	Like male, but lighter (Fig. 104d)	Like male (Fig. 104e)
antemedian line	Pink with faint white inner border	Pink with faint white inner border	Reddish brown with thin white inner border	Like male	Brown with pink inner and red outer border
oblique line	Pink with faint white inner border	Pink with faint white inner border	Reddish brown with thin white inner border	Like male	Like male
postmedian line	Dark brown with white outer border having a pinkish tinge	Pink with faint white outer border	Reddish brown with prominent white border	Brown with white outer border	Dark brown with black inner and pink outer border
Ocellus:					
anterior outer line	Pink	Pink	Reddish	Reddish	Brown
anterior inner line	Faint white	White	White	White	Black
anterior half	Pink	Pink	Reddish	Reddish	Yellow
posterior outer line	Black	Black	Black	Black	Brown
posterior inner line	Light yellow	Light yellow	Yellow	Yellow	Black
posterior half	Dove grey	Dove grey	Brownish	Brownish	Yellow
Shape of hyaline spot:					
male	Oval (Fig. 105a)	Oval (Fig. 105b)	Oval (Fig 105c)	Triangular (Fig. 105d)	Biconvex (Fig. 105e)
female	Triangular	Triangular	Oval	Triangular	Biconvex

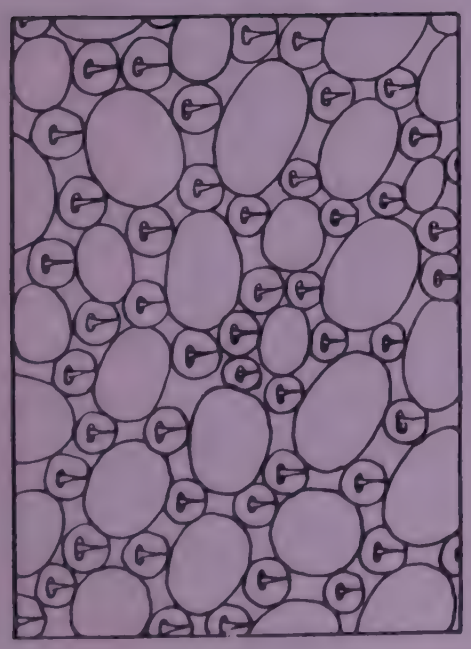


FIGURE 100. Follicular imprints of *A. proylei*

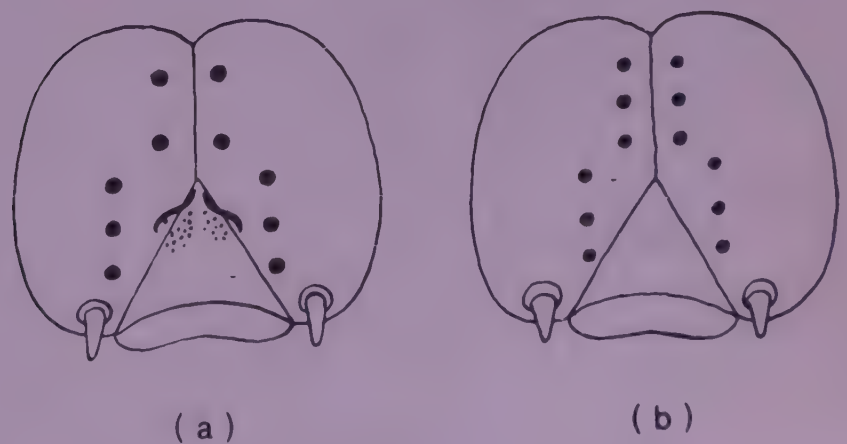
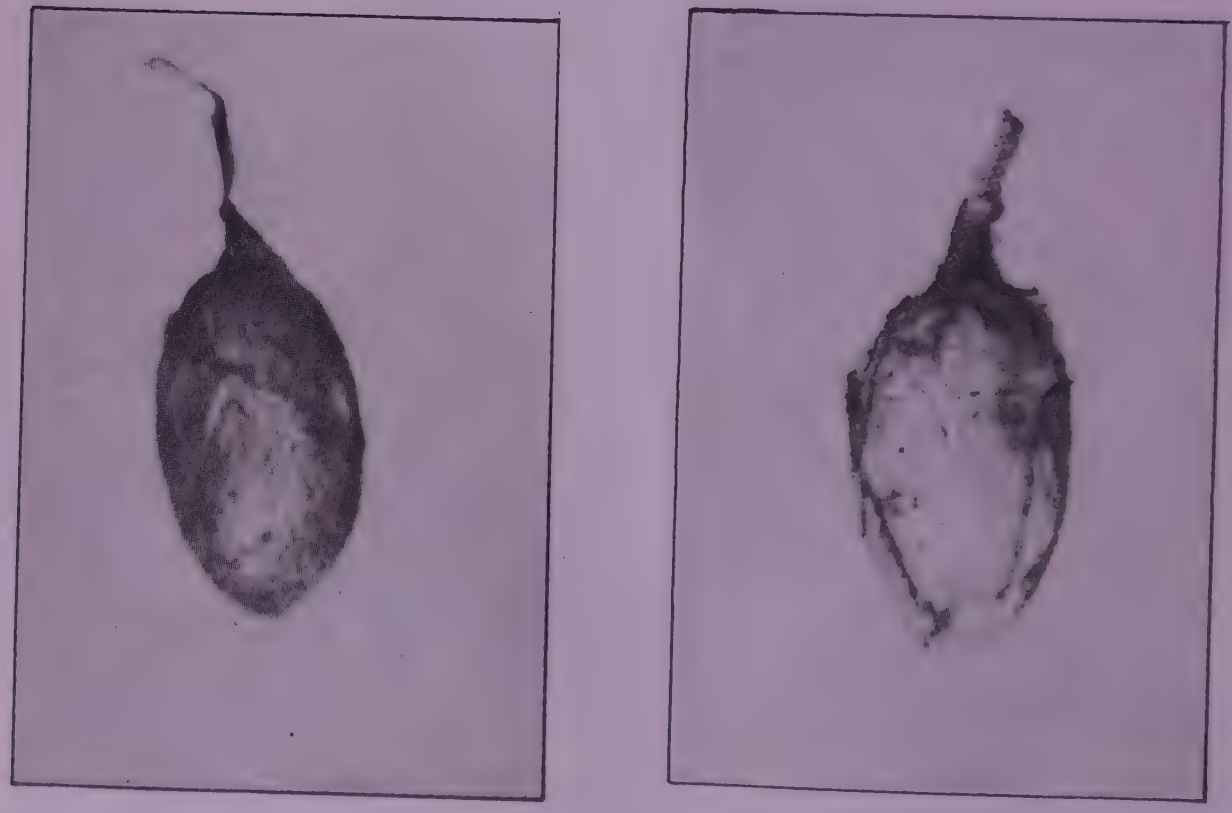


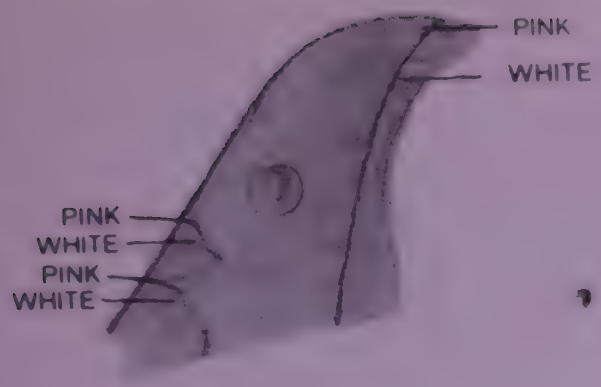
FIGURE 101. Spotting on the head capsule of (a) *A. proylei* and (b) *A. roylei*

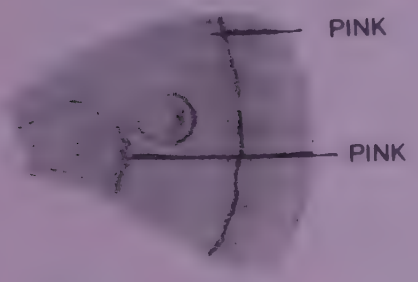
(a) (b) (c)



(d) (e)

FIGURE 102. Cocoons of temperate tasar:
(a) *A. proylei*, (b) *A. roylei*, (c) *A. pernyi*,
(d) *A. yamamai* and (e) *A. polyphemus*

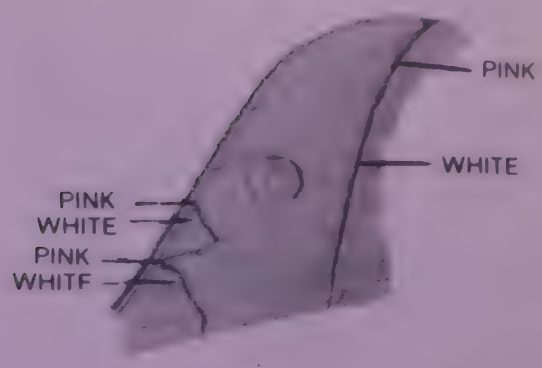




i

ii

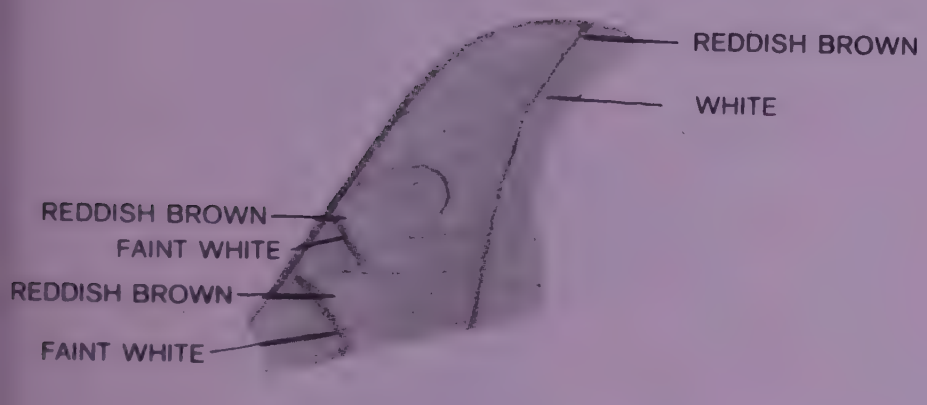
(a)

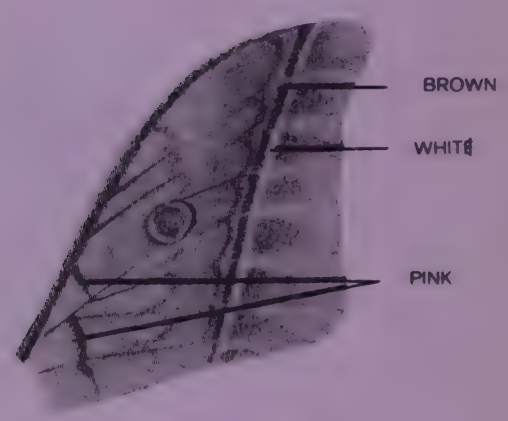


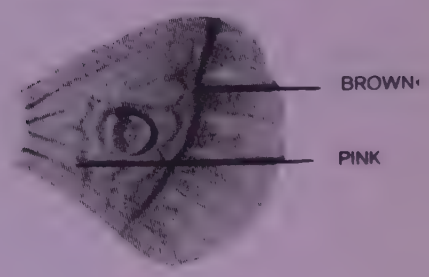
i

ii

(b)





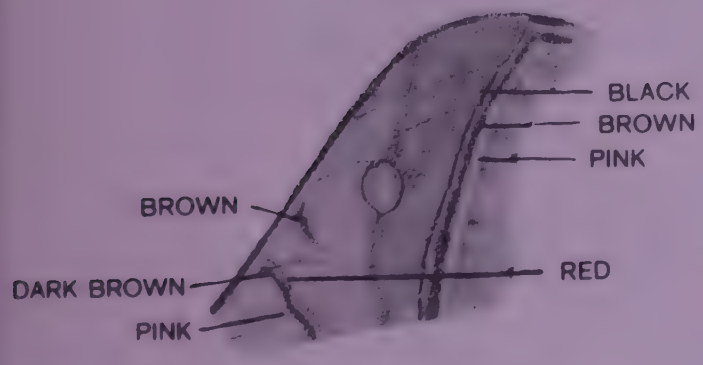


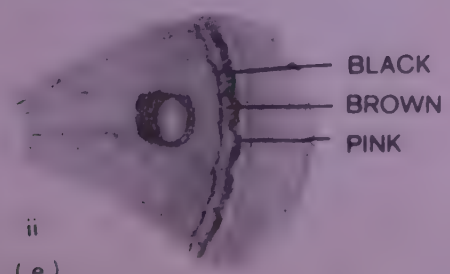
i

ii

(c)

(d)





i

ii

(e)

FIGURE 103.

Fore (i) and hind (ii) wings of male moths:
(a) *A. proylei*, (b) *A. roylei*, (c) *A. pernyi*,
(d) *A. yamamai*, (e) *A. polyphemus*

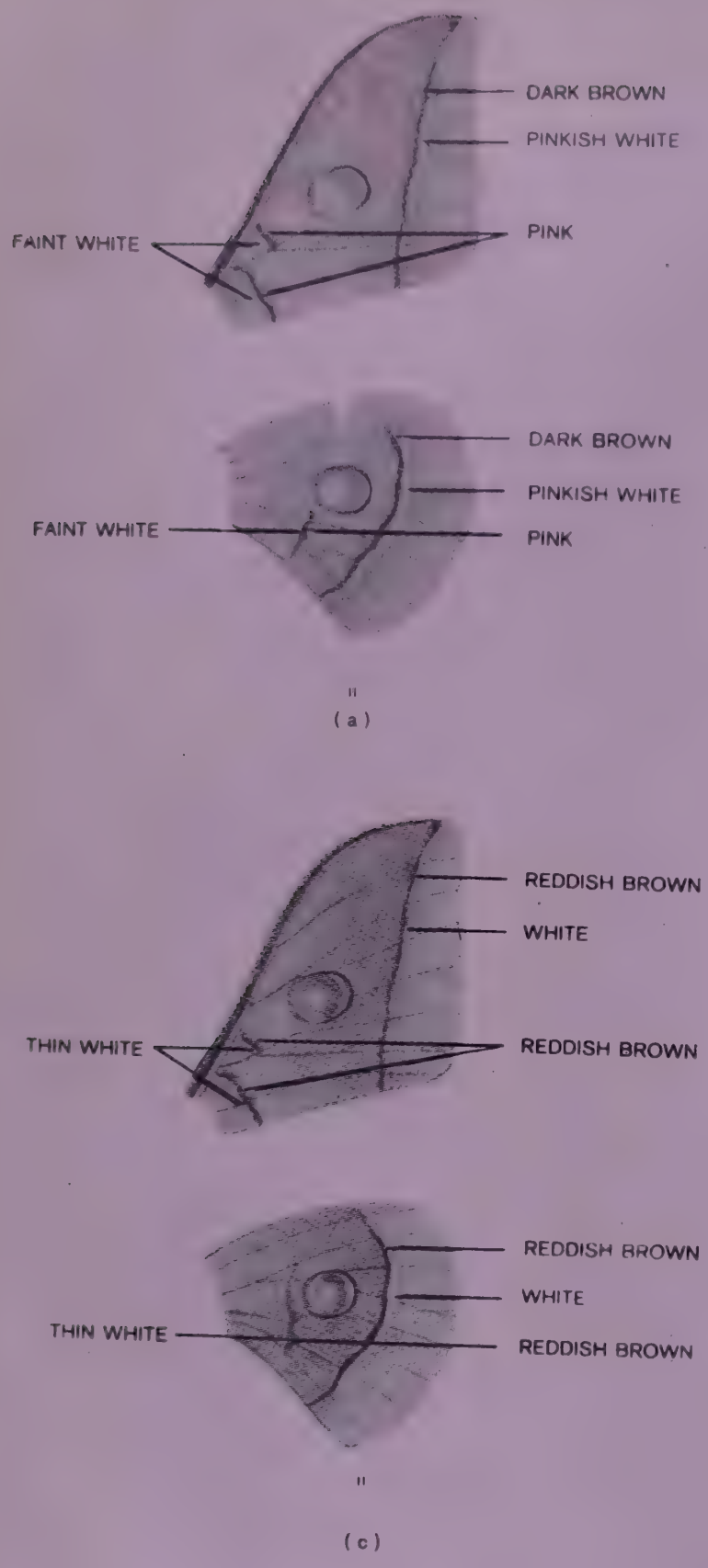
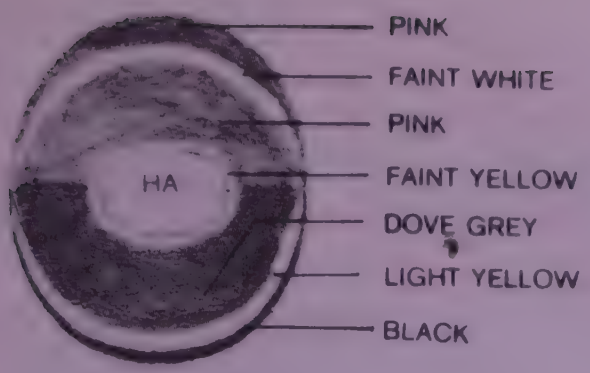
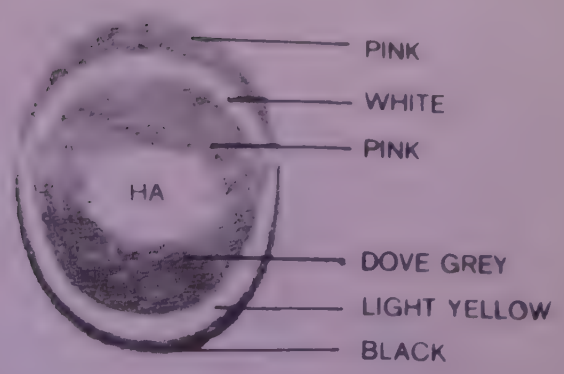


FIGURE 104.

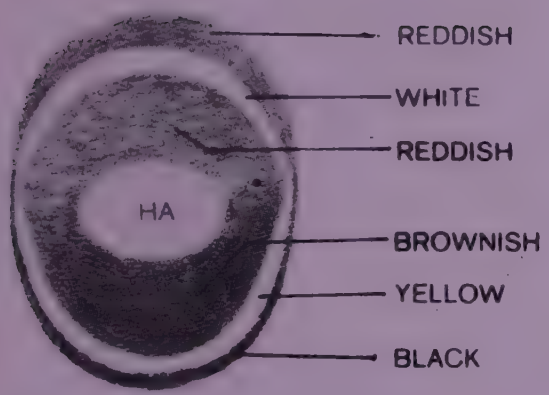
Fore (i) and hind (ii) wings of female moths:
(a) *A. proylei*, (b) *A. roylei*, (c) *A. pernyi*,
(d) *A. yamamai* and (e) *A. polyphemus*



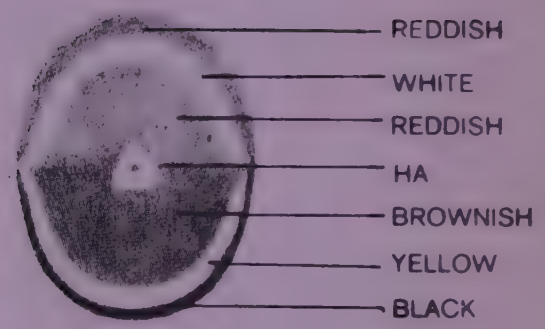
(a)



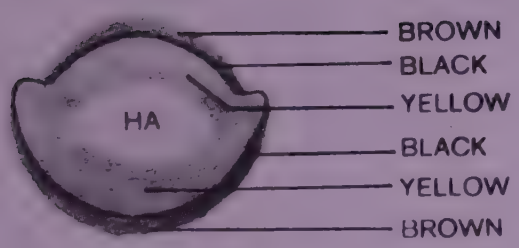
(b)



(c)



(d)



(e)

FIGURE 105. Ocelli of temperate tasar moths:
(a) *A. proylei*, (b) *A. roylei*, (c) *A. pernyi*,
(e) *A. yamamai* and (e) *A. polyphemus*

Chapter 17

ARBORICULTURE

The food plants of temperate tasar silkworm are mainly of the genus *Quercus* Linn. (oak). This very large genus of nearly 300 species is distributed throughout the temperate regions of the northern hemisphere and extends into the tropics and subtropics of South America, India, Malaysia and Australia, often above 600 m above sea level.

In India about 58 better known species of the genus are distributed all along the western sub–Himalayan range at 1 200 to 2 100m and in the eastern hilly tracts 700 to 1 500 m above sea level.

17.1 Primary food plants

The oak flora consists mainly of *Q. incana* Roxb. (banj. Fig. 106), *Q. ilex* L., *Q. glauca* Thunb. (phanat), *Q. semicarpifolia* Smith (kharshu) and *Q. himalayana* Bahadur (moru) in the western sub–Himalayan belt and *Q. serrata* Thunb. (uyung), *Q. semiserrata* Roxb. and *Q. dealbata* Hook. f. & Thomas (Figure 107) in the eastern belt. Of these, *Q. incana, Q. serrata, Q. delabata, Q. himalayana* and *Q. semiserrata* are the primary food plants of the temperate tasar silkworm.

FIGURE 106. *Q. incana* (banj)

FIGURE 107. *Q. dealbata*

17.2. Taxonomy

Some of the important taxonomical aspects of the genus *Quercus* are the following (51, 56):

Order: Falales Family: Fagaceae
Habit: large trees and shrubs, deciduous or evergreen.

Leaf: alternate, entire, toothed or lobed.
Flower: unisexual, incomplete, monoecious, minute or small (Figure 108).

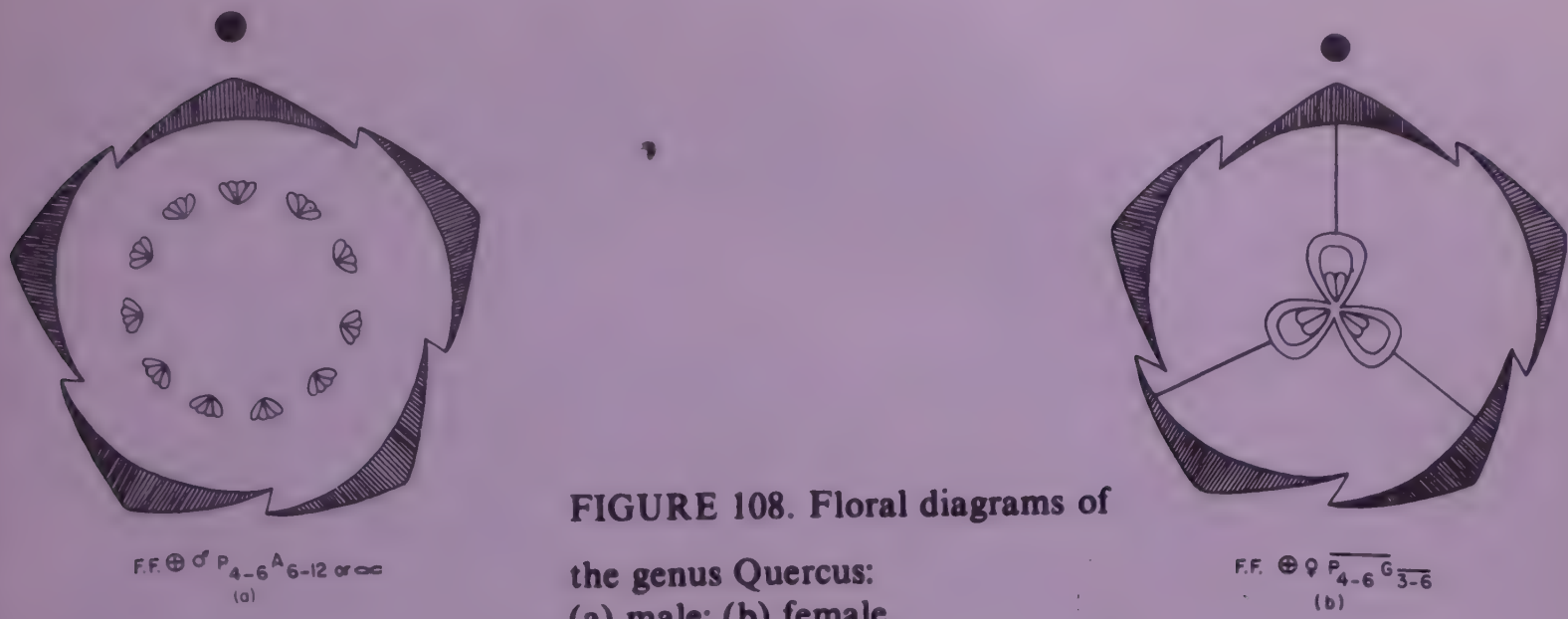


FIGURE 108. Floral diagrams of the genus Quercus:
(a) male; (b) female

Male: perianth four – to seven–lobed or partite, companulate, lobes imbricate; stamens indefinite, six to twelve, slender.

Female: perianth tube adnate to the ovary; staminodes minute or absent; ovary three–to–five–celled, three to five styles, short, two ovules in each cell.

Fruit: nut, edible.
Seed: One or two, thick fleshy cotyledons.
Sprouting: May and June.

17.3. Vegetative propagation

Propogation from seed, though common in the genus *Quercus* is not recommended, however, for large scale commercial plantations. Among the various methods of asexual propagation, inarching, vineer grafting (114) and air layering (32) have been successfully exploited. The procedure of air layering is described in Chapter 6.

17.4. Plantation and cultural operations

Temperate tasar larvae are fed on self–generated trees, which are so abundant in the forests that there is ample scope for converting them into systematic plantations. Under forest conditions the trees are naturally manured by shed leaves, and there is hardly any need for tillage.

17.5. Training

In the western sector the oak trees are mostly lofty (more than 7 m). In the eastern zone the oaks are generally medium–sized owing to large–scale cutting in the past by the local people, mainly for fuel. Hardly any systematic training–cum–pruning is practised in India. In Japan, oaks used as *A. yamamai* and *A. pernyi* food plants are trained to a height of 1 to 2 m every three to four years.

17.6. Cytology

The chromosome number of the genus *Quercus* is n = 12, most of the species being diploid (38, 198, 122, 126). An optimal stage of genome has already been achieved in this genus. Any diversity is attributed to chromosomal repatterning and gene mutations (126). The chances of polyploidy in this genus are limited; however, an instance of tetraploidy in *Q. dealbata* (164) and of triploidy in *Q. robur* (62) has been observed.

Chapter 18

GRAINAGE

The various grainage activities of temperate tasar silkworms differ considerably from the tropical tasar, primarily because of habit and habitat. Unlike other *Antheraea,* which undergo pupal diapause, *A. yamamai* diapauses at the egg stage. In the case of *A. proylei* certain grainage activities vary to some extent between the eastern region (700 to 1 500 m msl) and the western region (1 200 to 2 100 m msl), obviously because of climatological factors.

18.1. Preservation of seed cocoons

In the western region the preservation of second-crop (diapausing) seed cocoons of *A. proylei* poses almost no problems; but in eastern region, where emergence continues irregularly from the first week in December and the food plants do not begin to sprout until the first week of March, a large quantity of layings prepared during this period go to waste because of the nonavailability of suitable foliage.

The problem of irregular emergence has been overcome by consiging the seed cocoons in October to a higher elevation (about 1 800 m), where the average temperature does not exceed 15°C from November to February (162). During preservation the cocoons are hung in garlands. In the first fortnight of March the seed stocks are brought back to the plains, where emergence starts within a week and is completed in the short span of about fifteen days.

The optimum temperature for the preservation of diapausing cocoons of *A. pernyi* is 8–10°C in autumn, 5°C in winter and 18–22°C from February until emergence. The relative humidity should be maintained at 60–75%. The safest period for transporting seed cocoons is October and November. The nondiapausing cocoons are preserved instead at 20–22°C and 70–75% R.H.

In the case of *A. yamamai* the eggs laid in August hibernate and do not hatch until May. To avoid a considerable loss of laying due to delayed sprouting, the eggs are refrigerated at 5°C and removed to room temperature at the proper time (205).

18.2. Emergence

Unlike tropical tasar silkworm, *A. proylei* silkworms emerge between the hours 14:00 and 20:00 with maximum emergence at 16:00 to 18:00 hours. The optimum temperature and relative humidity for moth emergence are 26–28°C and 75–80%.

Emergence in *A. yamamai* reaches a peak at 21:00–22:00 hours and is completed by midnight. The best emergence performance has been observed at 25°C.

18.3. Coupling

The coupling aptitude under indoor conditions has proved to be quite satisfactory. Coupling starts about 3 to 4 hours after emergence and reaches a maximum at 20:00–22:00 hours. Coupling may continue for 24 hours under natural conditions, but 4 hours are considered sufficient. Decoupled male moths can be utilized a second and even a third time if there is a shortage of males.

The moths of *A. pernyi* prefer a temperature range of 18–22°C in spring and 22–25°C in summer, with 75% R.H. Coupling in *A. yamamai* starts after sunset, but the moths, unlike other species, decouple by dawn.

18.4. Egg laying

The moths are allowed to lay eggs in complete darkness in bamboo baskets or paper bags. Laying continues for 3 to 4 days, but 85–90% of the eggs are laid on the first day. The moths perform best at 24–26°C and 75–85% R.H. The average egg-laying capacity is only 125, less than that of tropical tasar.

The disease-free and disinfected eggs are maintained at 28°C and 70–80% R.H. Hatching starts in about 10 days, early in the morning, and is completed within 3 to 4 days; however, only the silkworms hatched in the first 48 hours are considered for rearing.

The optimum temperatures for egg laying and incubation in *A. pernyi* are 18–22°C and 16–18°C in spring and 22–25°C and 22–24°C in summer; the humidity requirement in both the seasons in about 75%. If necessary, the eggs of *A. pernyi* can be preserved at 0–4°C for 10 to 15 days without an adverse affect on their vitality (130).

The moths of *A. yamamai* prefer 25°C for oviposition and produce an average of 150 to 250 eggs. The eggs are soaked in 1–2% formalin for one hour. Before hatching 10–15 eggs are pasted with starch on a small piece of paper in a single row (205). The hatching percentage in *A. yamamai* is very low (30%).

18.5. Diapause

Incontrast to *A. mylitta* temperate tasar responds to photoperiod in both the larval and pupal stages (118, 189, 200). The photoperiodicity is perceived by the larvae through the integument rather than the ocelli.

In *A. proylei* a high percentage of the first harvest turns univoltine, thereby restricting the rearing to only one crop. This can be corrected by subjecting the pupae to a long-day (16-hour) photoperiod (110), in which case the moths emerge in 6 to 7 weeks. If the treatment is extended to fourth-and fifth-instar larvae, the moths emerge in 3 to 4 weeks. The technique has been highly simplified, and considerable success can be achieved even with a petromax or hurricane lamp.

Chapter 19

REARING

Temperate tasar silkworms are adapted to the lower temperature and the higher humidity of higher altitudes. Nevertheless, the various rearing operations, prerequisites, larval behaviour and certain other aspects are more or less similar to those for tropical tasar, except for differences in the rearing periods and techniques (see Chapter 9).

19.1. Rearing period

The rearing periods for *A. proylei* are March–May (first crop) and July–September (second crop), and for *A. pernyi* June–July and August–September. The larval span of the first crop is 35 to 40 days, whereas that of the second crop is 40 to 45 days. For *A. yamamai* the rearing period is June–July and the larval span extends to 45 to 50 days.

19.2. Larval behaviour

The larvae of *A. proylei* thrive at 25–26°C, and they become restless above 28°C and inactive below 15°C. The corresponding figures for *A. pernyi* are 18–22°C, 28–30°C and 8–10°C (130). The early stages require higher relative humidity (80–90%) than the advanced stages (70–80%).

The young larvae prefer succulent leaves and eats the entire leaf, including the midrib and even the petiole. They have been observed occasionally to suck water drops, probably as a consequence of their high humidity requirement. In contrast to tropical tasar silkworms, the moulting larvae of *A. proylei* manage to cast off their skin even if they are detached from the twig. Peeling of bark for cocooning has not been observed, and the ring and peduncle are very weak. Cocooning is completed in 2 to 3 days.

If hatched indoors, the newly hatched larvae of *A. yamamai* characteristically have difficulty in settling on to the foliage. While feeding, the advanced stages cut the leaves through the middle, causing a considerable waste of foliage (205).

The larval growth rate in *A. proyeli* is comparatively slow. The ponderal, linear and breadthwise growth from hatching to maturity is about 2 x 400, 12 and 10 times, respectively.

19.3. Rearing techniques

The two Indian temperate tasar regions, eastern and western are highly diverse in topography, climate and oak flora; thus the rearing techniques adopted for the two regions are different. In the case of *A. pernyi* the technique used in various temperate countries is more comparable to that of the western region. Temperate tasar silkworms respond more favourably to indoor conditions.

Eastern region: The eastern region offers a congenial range of temperature and relative humidity for rearing both crops. Furthermore, the prevailing food plants, *Q. serrata* and *Q. dealbata* are slow-maturing varieties, so the foliage remains succulent and suitable for the larvae throughout most of the rearing period. The availability of medium bush plantation (1–2 m) in continuous patches also contributes significantly to the yield.

In the eastern region the larvae of both crops are reared under indoor conditions through the first instar and then outdoors for the remaining instars, using the same technique discussed for tropical tasar silkworms in Chapter 9. In case of hailstorms, which usually occur in late spring, the larvae should be transferred indoors on cut twigs. Early instar rearing centres can be developed without investment on existing plantation.

Western region: In the western region where temperature and relative humidity during the first crop remain comparatively low, with hailstorms occuring toward the end, complete indoor rearing is suggested. The early stges should be reared according to the controlled technique, and the advanced stages can be reared either on cut twigs suspended over strands of stretched wire or spread on sieved split-bamboo mats. As larvae reared indoors receive a very short photoperiod, it should be supplemented by artificial means to at least 10 hours for fourth and fifth instars.

As temperature (24–28°C) and relative humidity (80–100%) during the second crop are fairly high throughout the larval span, it is suggested that the larvae be reared indoors only up to the third instar. The polythene enclosure need not be used, and the water drops must be removed from the leaves; also, the thatch of the rearing hut should be kept as dry as possible. The advanced stages may be reared outdoors by the conventional method, except during the hailstorms.

The principal oak variety of the western region, *Q. incana* is fast maturing and quite tall. The foliage becomes tough within a fortnight of sprouting, rendering it unsuitable for feeding the early stges. It co-exists, however, with the late-maturing *Q. himalayana,* the foliage of which remains quite succulent throughout the rearing period. Thus the early batches can be reared on *Q. incana,* and for the late batches *Q. himalayana* can be utilized.

Economics of rearing

The average rearing capacity of a rearer's family is 1000 to 1 200 disease-free layings(dfls) due to the small size of the layings and the low foliage consumption of the larvae. Without difficulty a harvest of 30 to 40 cocoons per dfl can be obtained.

Chapter 20

DISEASES AND PESTS

20.1. Diseases

A proylei and *A. pernyi* suffer from three types of diseases: virosis, bacteriosis and mycosis. In *A. pernyi* microsoporidiosis and a "short worm" disease have also been reported. *A. proylei* is less vulnerable to diseases than *A. mylitta* owing to the more congenial climate of the temperate zone.

Virosis: *A. proylei* larvae exhibits symptoms similar to those in *A. mylitta*. Virosis in *A. proylei* is caused by polyhedral inclusion bodies (PIB). In *A. pernyi* both nuclear (15) and cytoplasmic (182) polyhedrosis virus have been observed. The polyhedra range from traiangular to hexagonal in shape and may be either very large (7.5 microns) or extremely small (1.64 microns) when they occur in colonies (20,182). The polyhedra in pupa haemocytes are larger than those in larvae (190). In some cases the shape of the polyhedra depends on the strain of the virus (47). A mutant strain was observed to be hexagonal instead of the normal tetragonal tritetrahedral.

In *A. proylei* the usual mode of transmission is oral and transovum, but transovarial transmission is encountered in *A. pernyi* and *A. polyphemus* (180).

Virosis inflicts a high crop loss (10–15%) in *A. proylei* particularly during the late instars. Low temperature, high humidity and bad-quality food (8, 174) induce virosis.

Bacteriosis: Sealing of the anal lips, chain-type excreta and rectal protrusion with symptoms identical to those in *A. mylitta* have been observed in *A. proylei*. Three different symptoms — carrion, tuberculosis and paralysis — have been reported in *A. pernyi* (205). With carrion the larva become flaccid and sluggish. It starts vomiting, suffers from diarrhoea and dies within 48 hours. The main symptoms of tuberculosis are exhaustion and stunted growth. The infected larvae moult with great difficulty. On death they neither change colour nor decompose but dry up quickly. Paralysis is marked by general weakness prior to immobility.

The only pathogenic bacteria identified in *A. pernyi* are *Bacillus thuringiensis* (130) and *Serrata marcescens* (196). Bacteriosis is only transmitted orally through contaminated food. Respiratory troubles due to heat and humidity shocks (195) lead to closure of the spiracles and dysfunction of the digestive system followed by rapid multiplication of the pathogenic bacteria.

The loss from bacteriosis is less than from virosis. Of the three bacterial diseases of *A. proylei* sealing of the anal lips is the most common. Whereas first-and second-instar larvae rarely suffer from the disease, the fourth and fifth instars are more susceptible.

Mycosis: The symptoms of mycosis in temperae tasar silkworms are basically the same as in *A. mylitta* except that the conidiospores are white. The rosy-tinged black patches, which apper in the initial stages, cover the whole body and ultimately turn white.

Whereas no information is available regarding the causative agent of mycosis in *A. proylei* the fungus *Aspergillus flavus* is known to produce the disease involved in *A. pernyi*.

Transmission is through the integument and spiracles. Wounds accelerate infection (22, 191), as clotting provides a substratum for the saprophytic development of the pathogen (194). The loss due to disease is almost negligible.

Microsporidiosis: The disease known as pebrine has been reported in *A. pernyi* and *A. mylitta* but has yet to be detected in *A. proylei*. The symptoms and modes of transmission are similar to those observed in *A. mylitta*. It is caused by a *Nosema* species, the spores measuring 4.9 x 1.9 microns, which are slenderer than those found in infected *A. mylitta*. Sometimes the disease become epidemic and causes 90–95% crop loss.

Short worm disease: Larvae infected with short worm disease turn chrysalid and are unable to spin cocoons. The disease, which has not been observed in *A. proylei,* is occasionally found in *A. pernyi.*

The primary cause of the anomaly, apart from physiological shock, was found to be of microbial origin (194). Frequently, the chrysalides die, poisoned by the silk that has not been discharged.

20.2. Pests

Like tropical tasar, *A. proylei* is infested by various pests, such as tachinid fly, inchneumon fly, wasps, canthecona bug, reduviid bug, ants and mantis; but the incidence is comparatively low. In the two regions of the temperate zone, the loss is higher in the eastern region (20–25%) than in the western region (10–15%). The tachinid fly casuses considerable loss in the eastern region, while its incidence is almost negligible in the western. Larvae infested during early instars die before spinning. In the case of late infestation, though the larvae form cocoons, the pupae succumb. The parasite maggots render the cocoons unreelable by making holes at several places on emergence. Other pests are not of serious concern in either of the regions, as they collectively account for only 8–10% of the crop damage. *Sturmia sericariae* is another parasite of *A. pernyi* reported from Japan (205).

20.3. Controls

The control measures against diseases and pests in general are adopted from those used for tropical tasar. Strick microscopic examination of the mother moths for preparation of disease-free layings is indispensable to successful rearing. In Japan, pebrine infection in *A. pernyi* was reduced from 80–90% to 2–5% by proper examination and slection of seeds. Care should be taken to secure the embryos from thermal shock and the larvae from starvation. This is particularly necessary with *A. pernyi,* in which there is the danger of occult viruses being activated.

To check the damage to reelable cocoons by tachinid flies, the infested larvae should be isolated on the basis of the black scars on their bodies. The cocoons spun by these larvae should be stifled immediately to kill the maggots, so that they can be used for reeling like normal cocoons.

Chapter 21

BREEDING AND GENETICS

The breeding of *A. proylei* is a rather recent development. Current breeding programmes give due weight to the collection and maintenance of breeding stocks, selection and hybridization. Although certain interesting cytological observations have been recorded, the genetics of *A. proylei* is still an unexplored field.

21.1. Germ plasm

A. proylei has undergone localized rearing for several generations in different areas of the temperate tasar belt. These regional populations have attained more or less the status of ecotypes. For example, in the eastern temperate zone there are four stocks: M–south, M–north, M–east, and M–west (M = Manipur). Similarly, a number of breeding populations have been reported from the western zone. A number of indigenous *Antheraea* species, such as *A. frithii, A. roylei, A. compta, A. helferi* and *A. sivalica,* as well as the exotic species *A. polyphemus, A. yamamai* and *A. pernyi* also constitute rich material for breeding studies.

21.2. Selection

The existing variability in *A. proylei* justifies the introduction of selection breeding. As for quantitative characters, selection studies based on the maximum cocoon and shell weights (8 g and 1.2 g in males and 10 g and 1.4 g in females) have been initiated in Imphal, Uttar Pradesh, Jammu and Kashmir.

Other characters requiring immediate attention are fecundity, emergence and voltinism. There is an absolute need to increase the number of eggs per laying. Emergence is highly irregular and voltinism is very weak. Although experiments on seed cocoons preservation and photoperiodic treatment have solved these problems to a great extent (110, 162), there is still a serious need for stable races. In the breeding of *A. pernyi* and *A. yamamai,* selection for increased shell weight, higher shell ratio and fixed voltinism (bivoltine for *A. yamamai* and univoltine for *A. pernyi)* were given priority (205).

21.3. Hybridization

Inbreeding is not recommended for *A. proylei* at present or for *A. pernyi;* rather, emphasis has been given to hybridization.

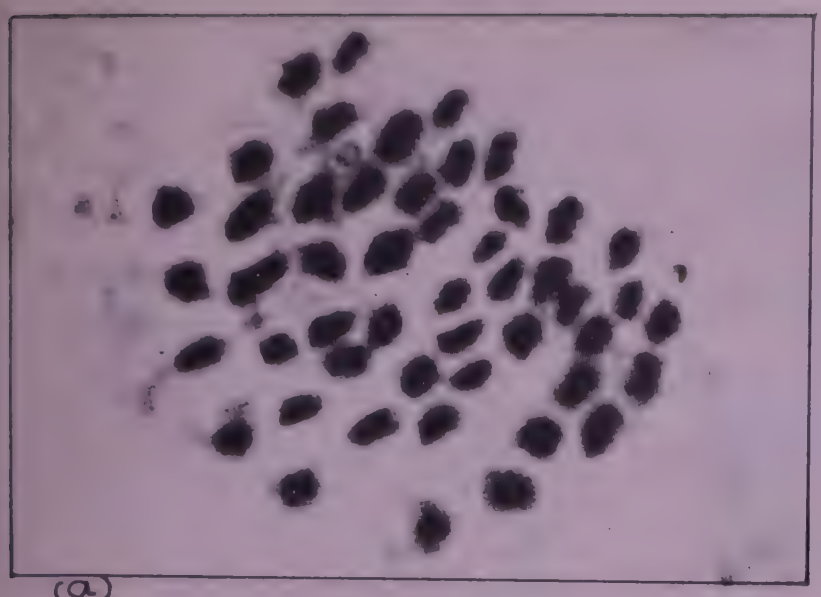
Interregional hybridization: To further improve the ecotypes, interregional crossings have been undertaken in both the eastern and western temperate regions. Initial trials in the eastern region with M–south × M–north showed a nearly 50% gain over mid–parent value (MPV). Similar efforts in the western region indicated that all the crosses between eastern and western stocks were superior in performance (106). Still better heterosis may be expected when local stocks are used as the mother parent and the non local stocks as the male parent.

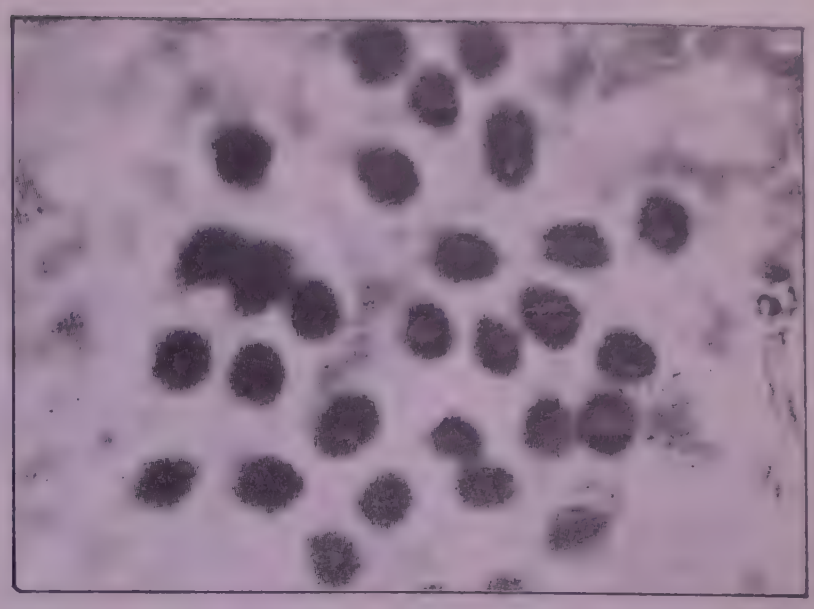
Taking a cue from its origin, *A. proylei* may be further improved by back crossing with *A. pernyi* the superior of the two parents. Attemps in this direction have met with some success at BC_1.

Interspecific hybridization: Only two crosses have been effected between the temperate tasar species: *A. pernyi* × *A. yamamai, A. pernyi* × *A. roylei* and their reciprocals (63, 71, 115). In the former the F_1 adults were sterile, whereas the later produced fertile progenies with a high degree of heterosis (Table 31), thereby giving birth to *A. proylei.*

21.4. Cytology

The haploid chromosome numbers of six *Antheraea* species of temperate zone have been determined (Figure 109): *A. pernyi,* n = 49 (77); *A. roylei* (western India), n = 30 (78); *A. polyphemus,* n = 30 (115); *A. yamamai,* n = 31 (115); *A. sivalica,* n = 31; *A. frithii,* n = 31. The *A. roylei* of eastern India exhibits an interesting numerical chromosome polymorphism of 30, 31, 32 and 34 (see Chapter 13).


(a)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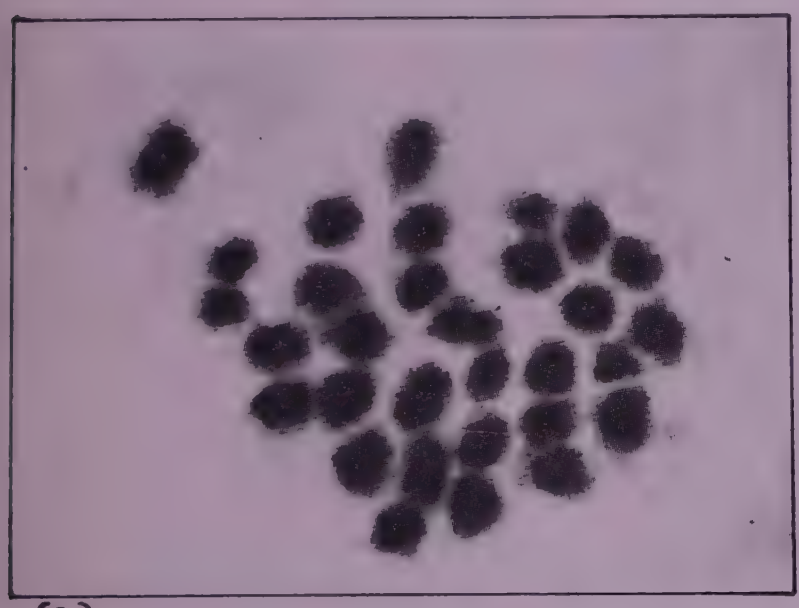
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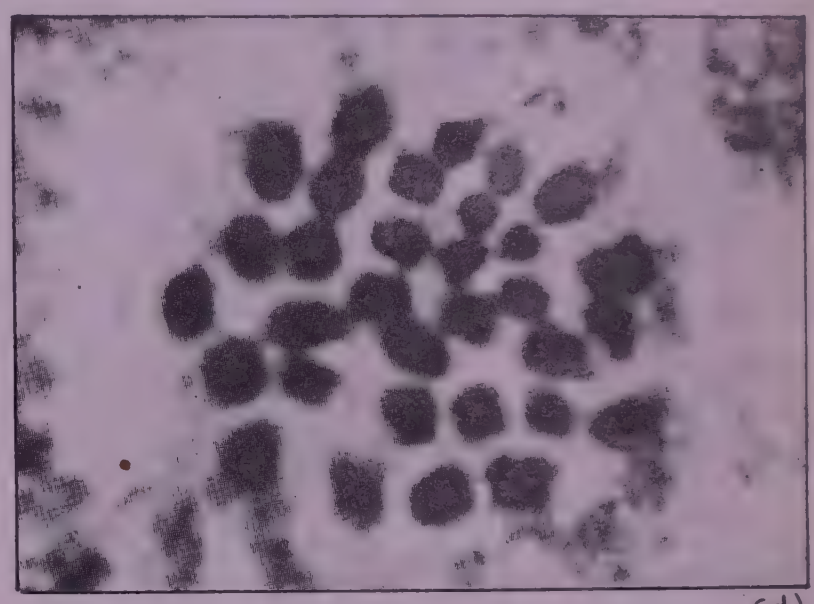
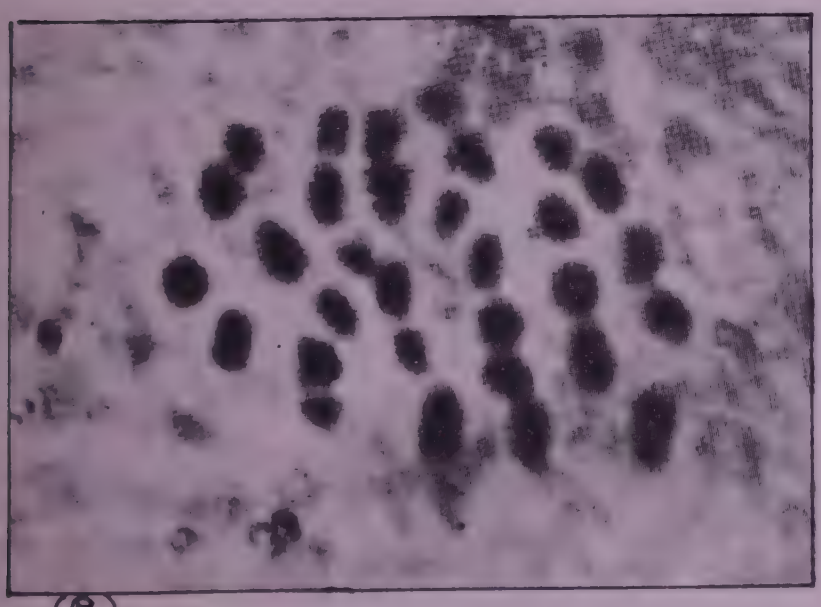

(d)


(e)

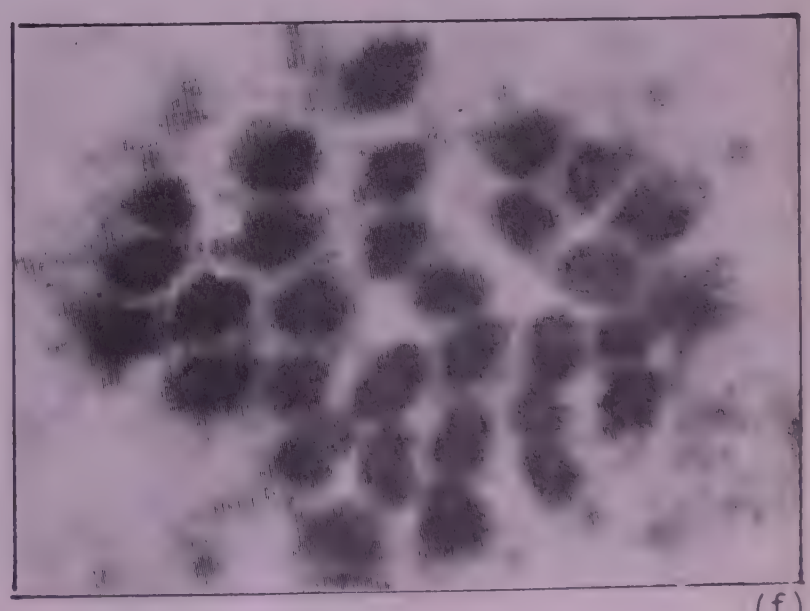
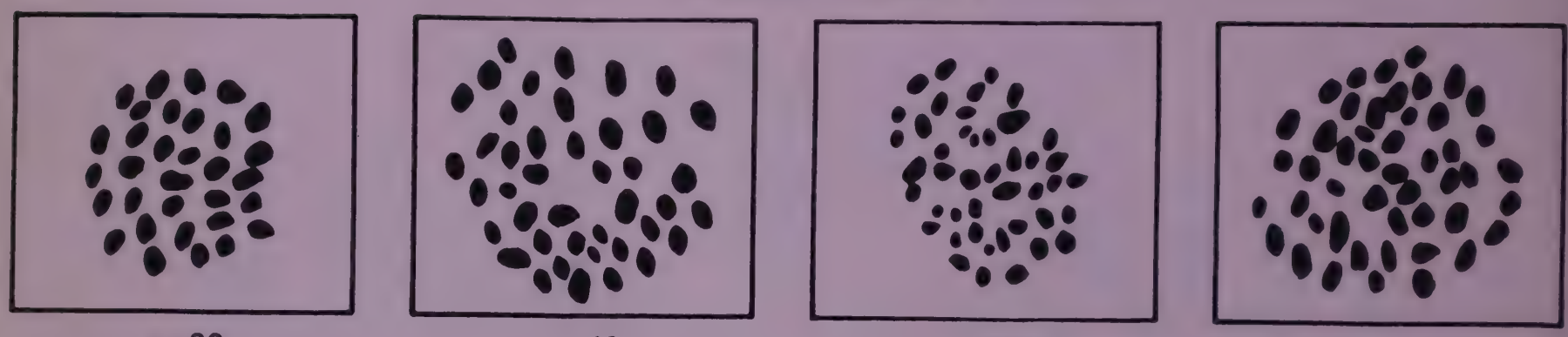

(f)

FIGURE 109. Chromosomes of (a) *A. pernyi*, (b) *A. roylei* (western zone, n = 30), (c) *A. roylei* (eastern zone, n = 31), (d) *A. roylei* (eastern zone, n = 32), (e) *A. frithii* and (f) *A. sivalica* (polar view of metaphase I)

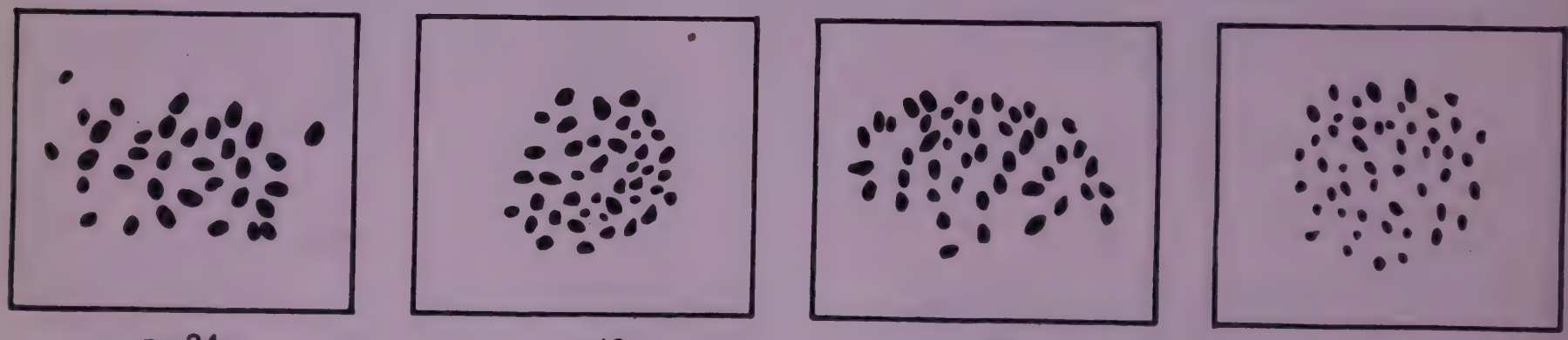
n=30

F_1 (A. ROYLEI×A. PERNYI)



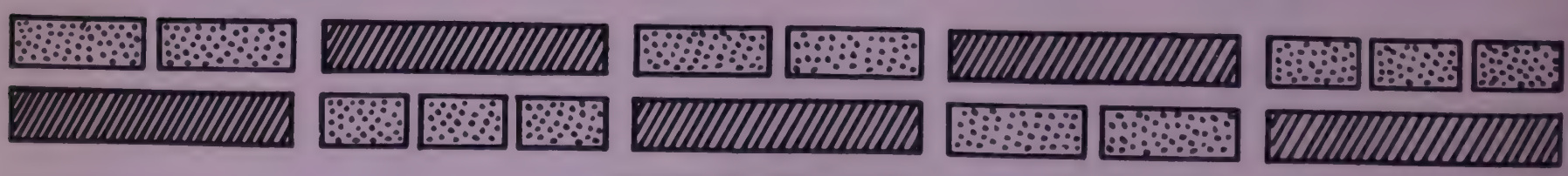
n=32 n=42 n=44 n=48

F_2 (A. ROYLEI×A.PERNYI)



n=34 n=42 n=46 n=49

BACK CROSS (A. ROYLEI·PERNYI×A. PERNYI)



PAIRING BEHAVIOUR

FIGURE 110. Chromosome pairing in the cross between *A. pernyi* and *A. roylei*

Table 31. Gain over mid-parent value (MPV) in *A. pernyi* x *A. roylei* at F_1

Species combination	Cocoon weight (g)	Reelable silk weight (g)	Reelable silk ratio (%)	Filament length (m)	Denier
A. pernyi	4.6	0.41	8.90	411.0	5
A. roylei	5.0	0.25	5.00	360.0	5
MPV	4.8	0.33	6.95	385.5	5
F_1	6.5	0.90	13.84	748.0	5
Gain over MPV (%)	35.5	169.60	99.13	94.0	-

A. proylei, despite the disparity in the chromosome numbers of its parental species, offers a rare example of fertility. Cytological investigations of the cross (90) revealed 30 chromosomal units at F_1, 32, 42, 44 and 48 at F_2 and 34, 42, 46 and 49 in the back cross *A. roylei* x *A. pernyi* with *A. pernyi*. The presence of 30 chromosomal units at F_1 indicates that 49 chromosomes of *A. pernyi* were arranged in the metaphase I plate so as to pair with 30 chromosomes of *A. roylei* and form bipartites,tripartites, etc. (Figure 110). If the number of bipartites and tripartites is 11 and 19, as has been suggested (192), the F_2's and back crosses would possess from 30 to 49 chromosomes.

The number of chromosomes in the F_1 hybrid of *A. pernyi* x *A. yamamai* were 30, 60, 63, 68 and 69 (115). This configuration has not yet been explained, since in case of sterility due to total lack of pairing the number of chromosomes at F_1 would have been 80.

21.5. Inheritance pattern in interspecific crosses.

Only two crosses have been studied in detail for inheritance pattern: *A. mylitta* x *A. frithii* (82) and *A. pernyi* x *A. roylei* (155), as well as their reciprocals.

A. mylitta x *A. frithii* – The hybrids inherited from *A. frithii,* such larval characteristics as the colour of the anal flap and claspers and the structure of body setae, while the characteristics contributed by *A. mylitta* were the number and arrangement of body setae. The colour of head capsule and body and the number and arrangement of tubercles were common to both parents and hybrids. The arrangement of tubercular setae in the hybrids followed the pattern of *A. frithii.* In structure and colour of cocoon, peduncle and ring the hybrids were similar to *A. mylitta,* but in cocoon size and peduncle lenth they were nearer to *A. frithii.* The moths were similar in certain characteristics to *A. frithii* and in others to *A. mylitta.*

A. pernyi x *A. roylei* – Most of the larval characteristics of the hybrid were common to both parents. The cranial spots were very similar to those of *A. pernyi.* The cocoons were bigger with a higher silk content; moreover, were single shelled, rather that double shelled as in *A. roylei.* The follicular imprint was like that of *A. pernyi.* Most of the moth characteristics reflected the dominance of *A. roylei* and only a few of *A. pernyi.*

Part-IV

MUGA CULTURE

The shimmering golden-yellow silk is referred to in literature from as long ago as 1662 B.C. Even today it occupies a very important place in the life and culture of the Assamese people regardless of community and caste. During the last few decades, however, there has been a substantial decline in the muga industry, particularly due to indiscriminate felling of food plants and frequent natural calamities, such as flood and drought.

The muga silkworm is cultivated only in Assam, possibly because its characteristic ecological requirements are found only in its natural abode. Eastern Goalpara and the south-western part of the Kamrup districts in lower Assam are the major seed cocoon areas, and there the trade is largely in the hands of tribal communities (Kacharis, Rabhas and Garo). Commercial rearing, on the other hand, is practised mainly by Ahoms in Sibsagar and Lakhimpur and to a lesser extent in Nowgong, Darrang and other districts.

The nature grown cocoons are utilized for seed, and over 80% of the commercial cocoons produced in the plains are transported by the traders to Sualkuchi village, where muga reeling and weaving are done on a large scale, almost as a monopoly.

Chapter 22

MORPHOLOGY

Heterogeneity and sexual dimorphism with regard to colour pattern are less pronounced in *A. assamensis* Westwood than in *A. mylitta* because of its limited geographical distribution. Being a member of *Antheraea,* most of its broad morphological characteristics are comparable to those of the other members of this genus.

22.1 Egg

The eggs are streakless, brownish, about 2.8 x 2.5 mm in size and 9 mg in weight. The follicular imprints consist of a single pattern with oval main cells (Figure 77h).

22.2 Larva

The newly hatched larva is characterized by prominent black intersegmental markings over the yellowish body with brown head. It measures about 7 x 1mm and weighs 7 mg. After the first moult the body turns green, while the head remains brown. A yellow body colour mutant has been introduced recently. At maturity the body length and weight are about 9 x 2 cm and 15 g (27). In the third instar the prothoracic hood marking consists of two prominent rectangular black marks, which in the subsequent instars are replaced by a pair of semilunar deep brown markings. The anal flap carries posteriorly a rectangular black mark in the third instar. In the fourth instar it becomes U-shaped, with the two arms joining the lateral line, and in the fifth instar it changes to a V with a black inner and a deep brown outer border. The markings on the clapsers during the five instars are shown in Figure 111.

The area above the planta has a rectangular black marking early in the third instar, which subsequently assumes the shape of a thin black band. The cream-colour lateral line of the first through tenth abdominal segments has a blackish brown upper and a yellow lower border in the fourth instar. The prominent yellow mid-ventral line extends from the first to the tenth abdominal segment.

The dorsal, upper lateral and lateral tubercles (DT, ULT and LT) are bluish and the lower lateral tubercles (LLT) are brown in the third instar; however, the first three change to brick red subsequently. The tubercular setae are pointed and blackish (Figure 78).

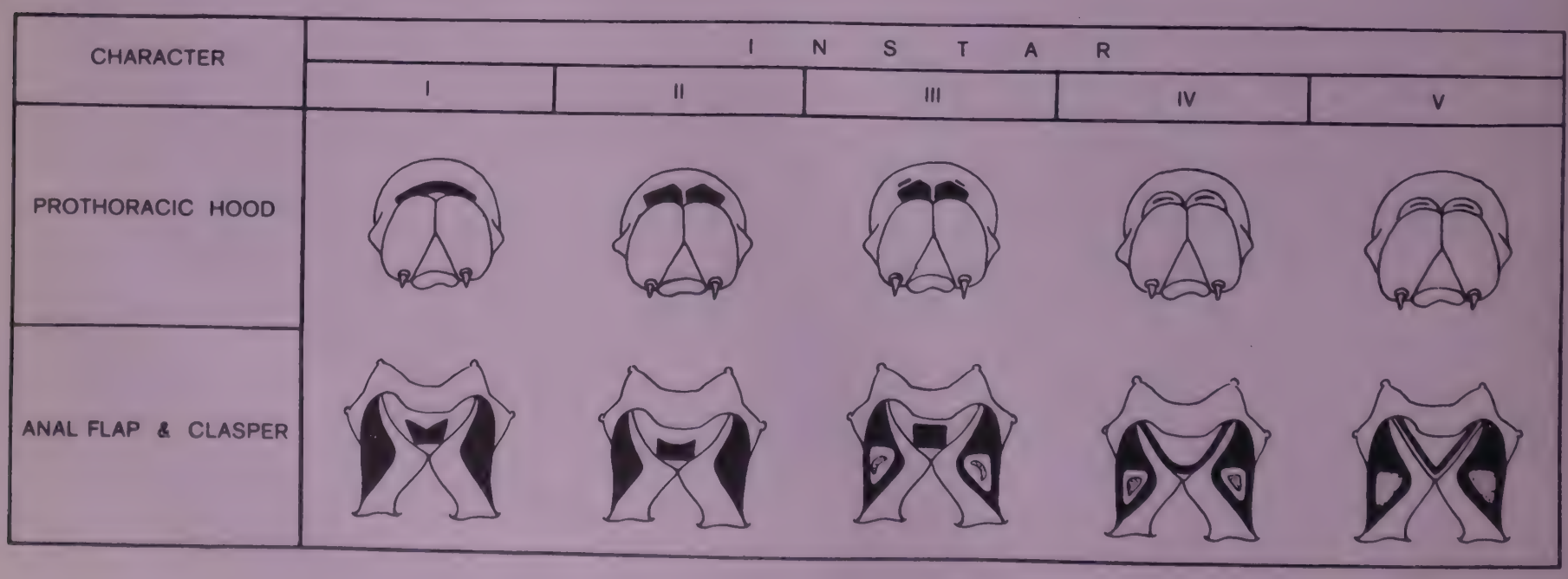


FIGURE 111. Markings on the prothoracic hood and the anal flap and claspers of *A. assamensis* during the five larval instars

22.3 Pupa

The pupa is copper brown, measures about 3.2 x 1.8 cm and weighs about 5.7 g.

22.4. Cocoon

The cocoon is single shelled, light brown, oblong, closed reelable and slightly flossy with a weak peduncle (Figure 112). It measures about 5.2 x 2.4 cm in size and weighs about 6.3 g, with a soft shell of 0.5 g and a 9.5% shell ratio. The cocoon is golden brown or glossy white.

22.5 Moth

The approximate body length of the males is 3.0 cm and of the females 3.5 cm.

Wing. The fore and hind wings are brown, rarely with a pinkish tinge. The wing expanse is about 13 cm in males and 15 cm in females. The wing area is smaller than that of *A. mylitta*. The area of the fore wing is 1 662 mm² in males and 1 857 mm² in the females, and the hind wing is 1 181 mm² in the males and 1 351 mm² in the females. The antemedian line (AM) and the oblique line (OL) have a white border on the inner surface. The postmedian line (PM) is bordered by a single white lining on either side in the males and by a white inner and a pink outer line in the females (Figure 113).

Ocellus: The ocellus of the female moth has a strikingly reduced hyaline area, which in the fore wing is almost dotlike (1 mm²) and in the hind wing a horizontal slit (3 mm²). In the male the ocellus of the fore wing measures about 14 mm² and that of the hind wing about 25 mm². In the female the area of the fore wing ocellus is about 23 mm² and that of the hind wing ocellus about 35 mm². The structure and colour pattern of the ocellus is shown in Figure 114.

FIGURE 112. Cocoon of *A. assamensis*

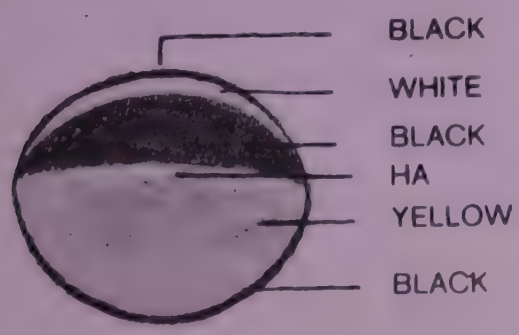
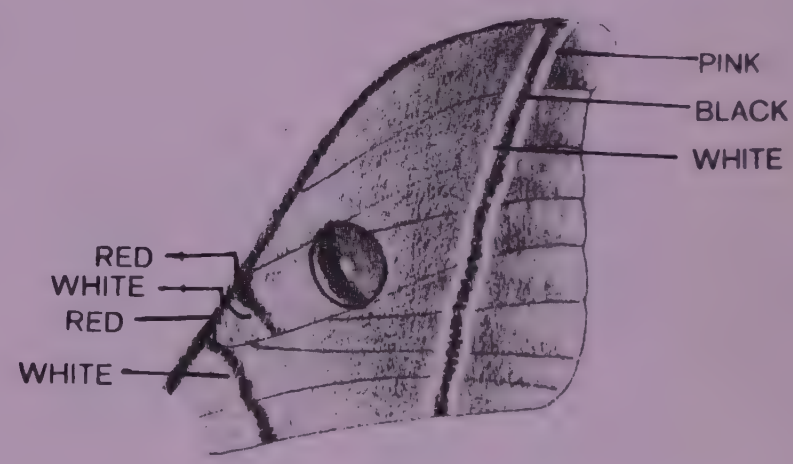
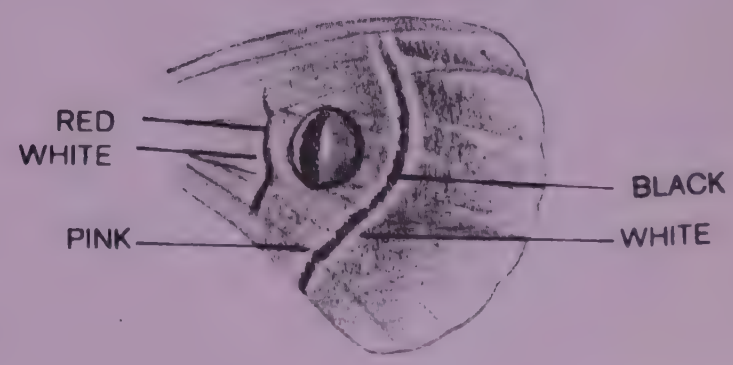


FIGURE 114. Ocellus of the *A. assamensis* fore wing



(a)



(b)

FIGURE 113. (a) Fore and (b) hind wings of the female moth

Chapter 23

FOOD PLANTS

The polyphagous muga silkworm feeds primarily on the leaves of *Machilus bombycina* King (som) and *Litsaea monopetala* Pers. (scalu). The other food plants of muga include *Litsaea citrata* Blume (mejankori), *L. salicifolia* Roxb. ex Wall. (digloti) *Michelia oblonga* Wall. (chapa), *Cinnamomum obtusifolium* Nees. (patihonda) and *Symplocos grandiflora* Wall. (bhomlati). *Machilus bombycina* King (som) is classified on the basis of leaf shape into sixteen morphotypes, of which the three more significant are Naharpatiya, Azarpatiya and Jampatiya. Naharpatiya is considered the best by muga rearers.

23.1. Distribution

M. bombycina and *L. monopetala* are distributed in India, Nepal, Burma, Khmer, Malaysia and Indonesia (56, 157). In India, these plants are common in Assam, Meghalaya, Arunachal Pradesh, Tripura, Nagaland, Manipur and North Bengal. *L. citrata* is found throughout the sub-Himalayan belt.

23.2. Taxonomy

The taxonomical aspects of the two important genera are enumerated in the following paragraphs (51, 56, 105).

FIGURE 115. *M. bombycina* (som)

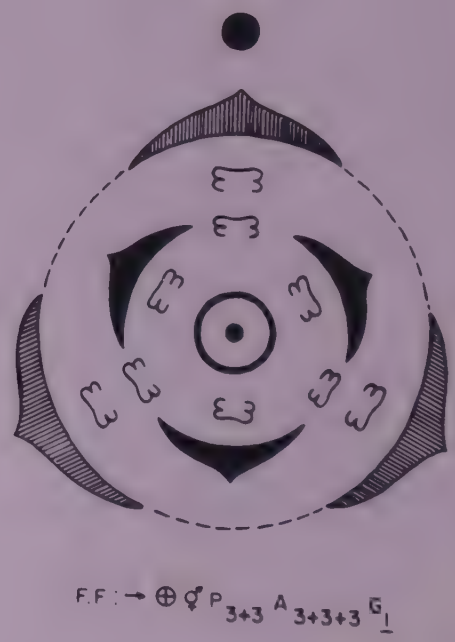


FIGURE 116. Floral diagram of *Machilus*

Machilus Nees.

Order: Laurales; Family: lauraceae
Habit: evergreen tree.
Leaf: simple, alternate, exstipulate, generally entire, penninerved.

Flower: regular, incomplete, bisexual, in axillary panicles, perianth tube short, six segments (Figure 116), imbricate in bud, persistent: androecium, nine perfect stamens, filaments of first and second series eglandular with introse four-celled anthers and four-celled anthers, staminodes of the fourth series cordate, perigynous; gynaecium ovary, one-celled, syncarpous, superior; ovules solitary, pendulous, anatropous.

Fruit: globose or oblong berry.
Seed: exalbuminous, pendulous.

Litsaea Lamk.

Order: Laurales; Family: Lauraceae
Habit: evergreen tree.
Leaf: alternate, rarely opposite or subopposite, elliptic or ovate, acute of acuminate.

Flower: dioecious, rarely monoecious, in a few sessile or pedicellate umbels, incomplete perianth tube ovide, companulate or very short, six to four lobed; androecium stamens, six, nine and twelve, rarely more or fewer filaments of first and second series eglandular and of third and fourth series (if present) two-glandular, four-celled anthers, introse; gynaecium ovary in male flower none or present in slender style, in female flower tricarpellary, syncarpous, one-celled, superior, ovule solitary, pendulous.

Fruit: drupe.
Seed: exalbuminous, pendulous.

23.3. **Propagation**

Both *M. bombycina* and *L. monopetala* are generally propagated through seedlings; however, clonal propagation is considered desirable. Limited success has been achieved in perpetuating *M. bombycina*, *L. monopetala* and *L. salicifolia* from stem cuttings (27) 15–20 cm long from one-year-old branches treated with hormone (Seradix B_3, IAA, IBA, L-NAA). The cuttings are planted the following spring in a shady and well-prepared nursery bed. Initial roots appear within 4 to 5 weeks and shoots come out after 2 to 3 months. *M. bombycina* can be perpetuated through ringing-cum-air layering (17).

23.4 **Training and pruning**

The muga food plants are usually not trained and pruned. Clipping the main root of seedlings at the time of transplantation induces a bushy growth, which is considered ideal for muga silkworm rearing. Simple but careful tipping of *M. bombycina* plants at an early age has also been recommended.

23.5. **Plant protection**

Control measures against some of the important pests and diseases of muga food plants are listed in Table 32. There should be an interval of 1 to 2 weeks after the application of pesticides before utilization of the plants for rearing.

Table 32. Controls against pests and diseases of muga food plants

Pest/disease	Damage	Control
Stem borer	Bores through the main trunk penetrating the innermost layer and moves upward causing a considerable reduction in foliage productivity.	See Table 8 on page 37
White ants or termites (*Microtermes, Odontotermes* and *Trinervitermes* spp.)	Attacks both young and full grown trees	See Table 8 on page 37
Gall insect (*Eurytoma chalcideae*)	Ugly galls form on both sides of the leaf	Rogor (0.5%) spray at 500–900 litre/ha from April to September.
Amphutu kani muga (*Cricula, trifenestra* and *C. andrei*)	The hairy caterpillars defoliate the plants.	Same as above.
Rust fungus	Tiny, pink or yellow pustules appear on the underside of leaves, followed by the development of dark-coloured spots on the upper surface.	Sulphur dusting at 10–12 kg/ha.

23.6. **Cytology**

Most of the *Machilus, Litsaea* and *Cinnamomum* species have 12 haploid chromosomes (123, 125); however, *L. glutinosa* Lour. C.B. Robin (syn. *L. chinensis* Lam.) has been reported to be a tetraploid (125), and *C. caudatum* Nees. a lower basic number (n = 10) has been ascertained (125). Wherever two species of the family Lauraceae coexist and have more or less similar flowering seasons, intermediate forms occur with normal meiotic behaviour (121). It has been suggested that speciation involved only minor changes in chromosomes, and the interspecific isolating mechanisms have been identified as ecological, geographical and temporal (125).

Chapter 24

GRAINAGE

Muga silkworm grainage is essentially the same as tropical tasar grainage (Chapter 18). A distinctive characteristic of muga culture is the use of overwintering mature-grown cocoons collected from the foothills of Brahmaputra valley for seed, whereas the commercial rearings are conducted in the plains of Assam. As almost the entire commercial production sent away for reeling, the frequent collection of nature-grown seed cocoons is necessary.

24.1. Selection of seed cocoons

The criteria of seed selection in muga culture are very different from those applied in other non-mulberry silk cultures. On the basis of visual inspection alone, the rearers select from the brood the larvae possessing a copper-coloured head capsule, two or three litters in the rectal part of maturity, five or more longitudinal striations on the litter and other favourable characters for seed stock.

24.2. Transport of seed cocoons

As the seed cocoons are transported over long distances, they require extremely careful handling. The traditional rearers carry the seed cocoons thinly spread in bamboo baskets, or even in cocoonage if pupation is not completed. They travel onfoot to avoid injuring the pupae.

24.3. Storage of seed cocoons

Because the muga silkworm is polyvoltine, long-term preservation of the seed cocoon is unnecessary. The traditional rearers store them in split-bamboo baskets hung from the ceiling to ensure protection from their enemies.

In the organized grainage centres the seed cocoons are stored in bamboo boxes (Figure 117) placed on wooden racks resting on antwells. The cocoons are spread in a single layer so as to allow adequate aeration. Temperature and relative humidity ranges of 25–28°C and 70–80% are suitable for seed cocoon storage.

FIGURE 117. Storage of muga seed cocoons in a bamboo box

24.4. Emergence

The development from pupa to moth takes about 16 days in summer and 30 to 35 days in winter. Emergence continues for 3 to 4 days in summer and 4 to 5 days in winter, reaching a peak at 17:00–20:00 hours and continuing as late as 22:00 hours. The emergence of the two sexes can effectively be synchronized by subjecting the male pupae to a low temperature.

24.5. Coupling

Coupling starts inside the cocoon storage box 30 to 45 minutes after emergence. Frequently, rearers resort however, to outdoor coupling, particularly if there is a shortage of moths. The female moths are tied on "kharikas" which are then hung outdoors. Mechanical coupling by hand can also be used, but its success depends largely on the skill of the operator.

The coupling performance is best in complete darkness. The optimum temperature and relative humidity for coupling are 25-28°C and 75-80%, however, coupling may take place at temperatures and relative humidities as low as 22°C and 70%. Coupling may last for 24 hours under normal conditions, but 3 hours time has been found adequate. The traditional rearers decouple the moths by moving a torch near them. The successful utilization of male moths for a second coupling has been reported. In the absence of a female counterpart the males can be preserved at low temperature for 1to 2 days, but the coupling aptitude is somewhat affected.

24.6. **Egg laying**

The fertilized female moths are tied to kharikas with about 10 cm of cotton thread, thereby allowing them movements that facilitate laying. The kharika (Figure 118) is a bundle of dried grass, locally known as "ulukher", about 1 cm in diameter with a hooking arrangement at the proximal end. It varies from 30 cm to 1 m in length depending upon the number of moths to be accommodated. The moths are tied 25 cm apart on the kharika so as to give them adequate surface for oviposition.

The kharikas carrying fertilized female moths are hung vertically in rows with the help of string in the grainage room. Moths prefer complete darkness for egg laying. The oviposition commences after sunset and is largely completed by midnight. The eggs are laid in groups of 8 to 10 held together by meconium. Laying continues for 3 to 4 days. The maximum laying, 60 to 70%, occurs on the second day, while 20 to 25% and 5 to 10% of the eggs are laid on the first and the third day, respectively. The average laying capacity is 150 to 250 from May to October, but it declines sharply to 80 to 100 during the winter.

The traditional rearers neither examine the mother moths nor disinfect the eggs, although it would be advisable to carry out these operations as suggested for tropical tasar (Chapter 7).

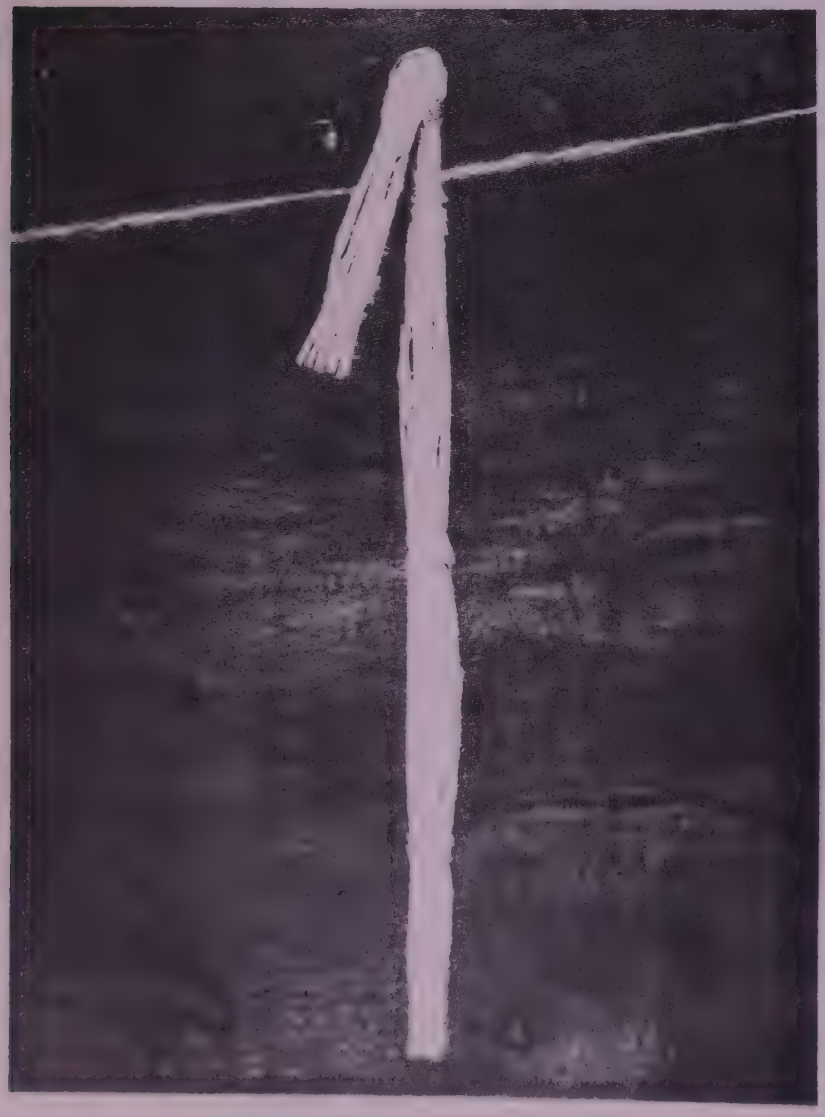


FIGURE 118. A kharika for coupling and egg laying

24.7. **Hatching**

The kharikas carrying eggs (Figure 119) are also kept indoors, preferably in trays. Hatching takes 7 to 8 days in summer and 14 to 15 days in winter. Whereas an average hatching percentage of about 90% has been observed during the summer, it is slightly lower (70–75%) and irregular during the winter; however, this disparity can be eliminated by proper incubation of the eggs.

Hatching usually commences in the morning hours — 4:30–6:00 in summer and 7:00–9:00 in winter — and is completed within three days. The maximum hatching of 75% occurs on the first day, while the hatching rate on the second and the third day is 20% and 5%, respectively. To ensure uniformity in the population, the eggs hatched on the third day are not used for rearing.

FIGURE 119. A kharika with muga eggs

Chapter 25

REARING

Unlike tropical and temperate tasar silkworms, *A. assamensis* is polyvoltine; however, as they are reared outdoors, the various aspects of rearing more or less resemble those of tropical tasar, except for indoors cocooning.

25.1. Rearing period

Rearing is conducted throughout the year, yielding five or six crops annually. These crops are designated by local names based on rearing months. The larval span varies by season, mainly because of the difference in temperature (Table 33).

Kotia and Jethua are large-scale crops for the production of reeling cocoons, whereas the remaining crops are used only for stock maintenance and seed purposes.

25.2. Larval behaviour

The muga silkworms have a high humidity requirement, which is largely satisfied by the high annual rainfall (2 000–2 100 mm) throughout the rearing belt. They can sustain a very wide range of temperature (Table 23); however, temperatures above 35°C combined with less than 65% R.H. makes the larvae restless and causes heavy mortality. The optimum temperature and relative humidity ranges are 24–25°C and 75–80%. The occurrence of diapause in the wild population inhabiting the foothills of the Brahmaputra vally is a consequence of the very short day and low temperatures during the winter.

Like the advanced-stage larvae of *A. yamami,* the early instars of muga silkworm cut the leaves through the middle. Like *A. proylei,* the late instars, consume the midrib and petiole, and they suck dewdrops. The larval growth rate is also more or less comparable to that of *A. proylei.*

Table 33. The muga crop seasons

Crop	Rearing months	Temperature (°C)		Relative humidity		Larval span (days)	Remarks
		Max.	Min.	Max.	Min.		
Jarua (winter)	Jan.–March	29	13	91	71	50–55	Important seed crop
Jethua (summer)	May–June	34	21	93	75	27–33	Second-best commercial crop
Aherua (early rainy season)	June–July	33	26	93	79	22–28	Seed crop
Bhadiya (late rainy season)	July–Aug.	34	26	92	77	25–31	Most important seed crop
Kotia (Autumn)	Oct.–Nov.	30	19	91	75	26–32	Best commercial crop

The ripened muga larvae have the peculiar habit of moving collectively toward the trunk base at dawn for cocooning. The ripening may commence at any time of the day. The larvae have to be picked up, as otherwise they travel long distances in the grass in search of a suitable cocooning place. Cocoon formation starts in the evening and is completed within 3 to 6 days, depending on the season. As in *A. proylei* the ring and peduncle are quite weak and almost rudimentary.

25.3. Rearing technique

Attempts to rear even the early stages of muga silkworm under indoor conditions have not yet met with success. Mounting is carried out in the morning. The kharikas are tied with straw rings on the main trunk of the trees 1.5–2.0 m above the ground. It is desirable, however, to place them on small twigs, so that the newly hatched larvae are not exposed to attack by their enemies and are able to reach tender foliage immediately.

The kharikas are placed either on the eastern or the southern side of the bush for adequate sunlight. The number of layings is adjusted so as to avoid transfer until third instar. Soalu is more efficaceous than som for feeding the early stages.

To control the downward movement of the larvae, a few straw bands are tied in succession on the main trunk and thick lateral branches. The larvae which cross the barrier are collected and placed on a triangular bamboo sieve known as a "chaloni" (Figure 120), which is then hung on a leafy twig by means of a bamboo stick.

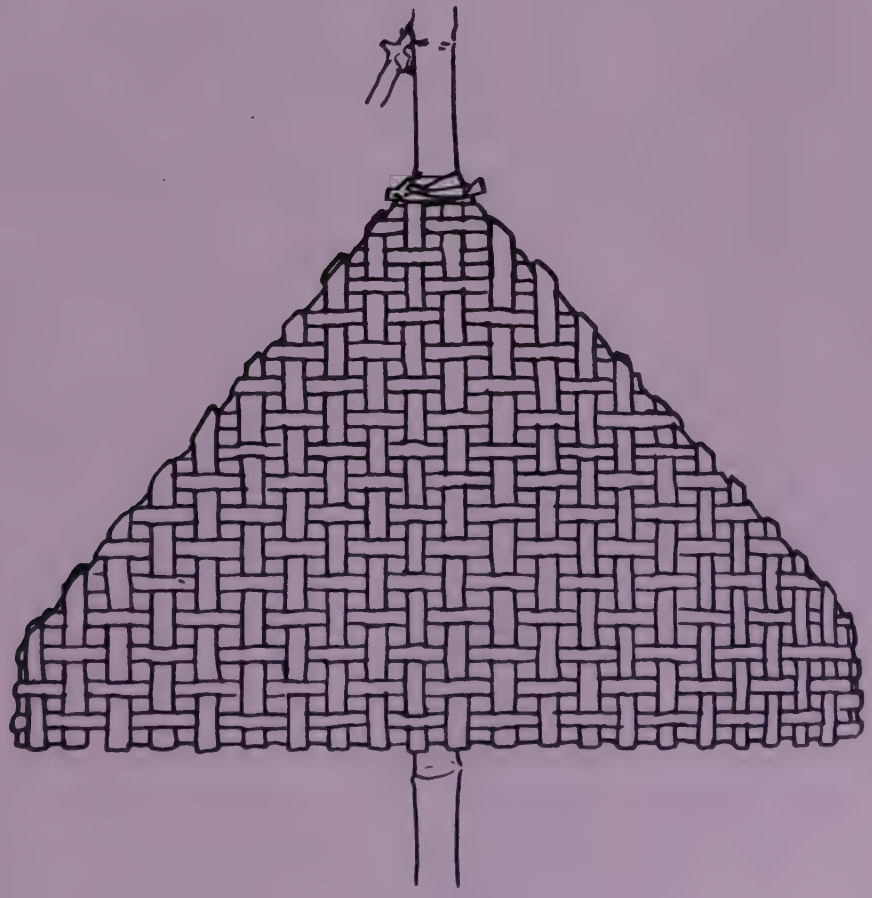


FIGURE 120. A chaloni for transferring larvae

For cocooning the descending mature larvae are collected in a chaloni in the evening and placed either in a pit or a bamboo basket, above which a bundle of dry leafy twigs, or jali (cocoonage), is placed. The larvae gradualy crawl onto the jali for spinning. Moist leaves are observed to produce cocoons of inferior quality. Twigs of a singori, som, soalu, mango, jackfruit and azar, for example, are preferred for cocoonage. The glaze of the cocoons is better if singori jali is used. The size of the jali depends on the number of larvae (usually 500–1 000) to be mounted for cocooning. The jalis with spinning larvae are hung indoors on wire about 2 m above the floor, and a piece of hollow bamboo (15–20 cm) is placed at the upper end to halt the upward movement of the larvae (Figure 121). Cocoons are harvested on the fifth day in summer and the eighth day in winter. If a population is being raised for seed, it is desirable to separate the sexes by the genital markings on the mature worms and use separate cocoonage to facilitate grainage operations.

25.4. Characteristics of muga rearing

Muga silkworms reared on young (4 to 5 years) mejankori bushes yield glossy white rather than brown cocoons. The survival rate on mejankori is very low, as only the more vigorous and healthy worms can thrive on it. Chapa plants are also reported to yield glossy white cocoons. Mejankori and chapa silks are produced chiefly in Jorhat, Assam.

In the foothills, as has already been pointed out, muga silkworms grow vigorously and can be maintained in a wild state year round. Congenial climatic conditions and rearing on soalu promote healthy growth, and they pass the winter in a dormant state.

In the plains the weather is favourable only in autumn. The soil remains water logged in the rainy season, adversely affecting both the silkworms and the food plants; moreover, hailstorms and gusty winds during the spring, climatic fluctuations and heavy rains in summer and intense heat during August and September cause severe damage to the population. Being polyvoltine, the larvae have to withstand the unfavourable winter conditions. Also, muga silkworms are reared so far as the food plant is concerned, mainly on one food plant: som. All these factors are probably responsible for the rapid deterioration of the muga population in the plains.

25.5. Economics of rearing

An average harvest of 50 cocoons per disease-free laying can be obtained through systematic operations in the two chief commercial corps, Kotia (autumn) and Jethua (summer). Muga cultivators, particularly those engaged in seed production, are able to rear 250 to 300 dfls per crop.

FIGURE 121. A jali for muga cocoon formation

Chapter 26

DISEASES AND PESTS

26.1. Diseases

The muga silkworms are vulnerable mainly to three types of diseases (58): bacteriosis, microsporidiosis and occasionaly virosis (95). Mycosis has not yet been detected.

Bacteriosis . Chain type excreta (also known as flaccid worm) and rectal protrusion have been reported in muga silkworms. The symptoms are virtually similar to those in *A. mylitta* (92).

Very little is known about the causative agents. The disease accounts for a nearly 30% crop loss. The incidence is highest in the summer crop, and late-instar worms are more susceptible. Unsuitable leaves and over crowding induce the disease (18).

Microsporidiosis : As in other silkworms, the most striking symptom of microsporidiosis is the appearance of black spots on the body integument; however, in muga silkworms the spots are of two types: smaller in some cases and notably bigger in others. Worms with the latter symptom, if they survive, moult five times instead of the usual four.

The disease is caused by a microsporidian of the genus *Nosema*. The disese is transmitted both orally and transovarially, as well as by insect vectors to some extent. The incidence of the disease is of sporatic nature being less frequent during spring and autumn but causing a 20–30% crop loss in the rainy season.

Virosis: The virosis symptoms are almost identical to those in *A. mylitta*. During the early stage of infection the body of the larva typically becomes flabby.

A virus characterized by inclusion bodies is responsible for the disease. The inclusion bodies are slightly angular (27) and quite different from those in *A. mylitta*, *A. proylei*, *A pernyi* and *A. yamamai*.

Oral transmission takes place through contaminated food. Transovum transmission also occurs, but there is no evidence of transovarial transmission. The loss due to virosis is almost negligible.

26.2. Parasites and predators

As muga silkworms are reared outdoors, they are subject to attack by a number of pests. Tachinid flies, such as *S. sericariae*, *Tricholyga bombycis* and *Mascicera* grandis (= *B. zebina*), have been reported to parasitize the larvae. The common predators of A. mylitta — namely X. pedator, G. furcellata, H. bipapilla and *S. collaris* - also account for nearly 40% of crop damage. The biology and life cycle of *S. sericariae* is similar to that of *B. zebina* (Chapter 11).

26.3. Controls

Diseases: The rearing of disease-free layings, the disinfection of eggs and equipment and the maintenance of optimum population density (18) are the major preventive measures against diseases. Since fluctuations in temperaure during the embryonic stages has been observed to induce virosis (27), care should be taken to incubate the eggs of the optimum temperature.

Apart from microscopic examination, the pebrine disease can also be checked by exposing the cocoons to 33.8°C and 55–65% R.H. for 15 hours in the prepupal stage (27). The treatment of eggs with hot water (40°C) for 30 minutes 36–40 hours after oviposition also helps control this disease.

Pests: Fly pests can be controlled by preventing the emergence of adults from the maggots. Infected and dead larvae should be collected and burned. The infected cocoons should be stifled before the maggots emerge from them (Chapter 20).

Chapter 27

BREEDING AND GENETICS

Very little is known about muga breeding and genetics of *A. assamensis*; however, analysis of the breeding potential, of the collection and maintenance of breeding stocks, hybridization and genetic and cytological studies have recently been undertaken.

27.1. Breeding stocks

The muga fauna is comprised of a few diapausing and nondiapausing ecotypes and strains.

Nondiapausing stock

Halflong green: The stock of green muga silkworm, originally collected from the wild populations of Halflong, has passed sixteen generations and is being maintained in the germ plasm bank. It is multivoltine, producing five or six generations per year. The yolk of this ecotype is green. Other wild green ecotypes from different places have more recently been brought under the semidomestication programme.

Yellow mutant: The yellow mutant strain has been isolated from the natural population and maintained in pure form (at this writing, for nine generations). Like the Halflong green, it is multivoltine. The strain is reported to be more resistant to diseases. The yolk of this mutant is yellow.

New segregants: In the green population there are variants with a light green or a greenish yellow body. These are known, respectively, as kamini and kukurbahi. In the kamini the tubercles are bright coloured, and in the kukurbahi they are dull. These two variants are in the process of purification.

A study of the quantitative cocoon characters of Halflong greens and yellow mutants over ten generations revealed fluctuations in vigour from generation to generation (Figure 122) with practically no deterioration (158). The fluctuations have been attributed to a "physiological state" caused by the seasonal influence coupled with nutrition.

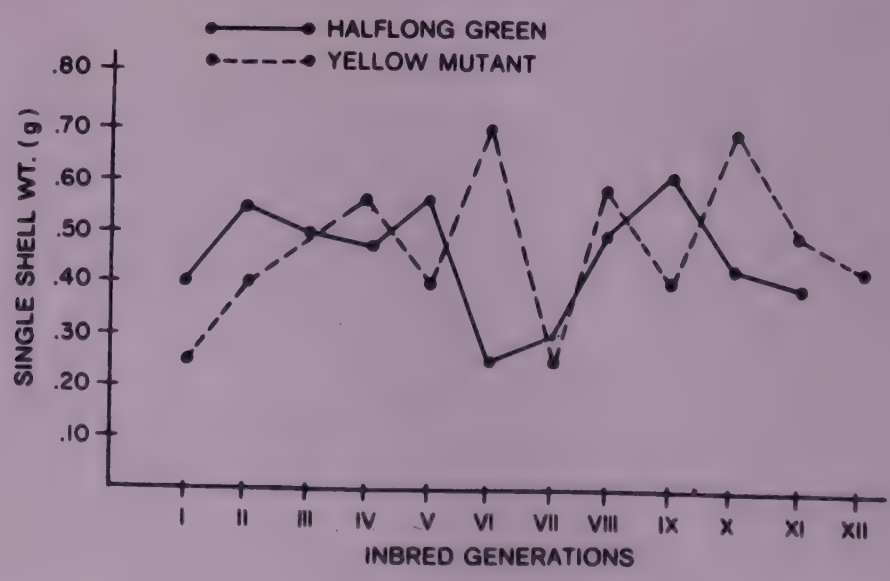


FIGURE 122. Trend in the shell weight of Halflong greens and yellow mutants over ten generations

Apart from the exploitation of their heterosis, these stocks will solve the seed problem in the plains of Assam (Chapter 24) by ensuring stable crops, hitherto unknown in muga culture.

Diapausing stock: Hibernating pupae are found among the seed cocoons collected from the foothills. The trivoltine strain undergoes pupal diapause for 5 to 6 months from September to March. They are hardy and vigorous in their quantitative characters. Some of their morphological features are quite distinct from those found in the multivoltines. The stock is being maintained in a semidomesticated condition. Hybridization with the multivoltines might result in vigorous trivoltine progenies, which would eliminate the hazardoux winter rearing and thereby reduce the cost of production.

27.2. Exploitation of heterosis

Hybricization between ecotypes or strains: Attempts have been made to ascertain the combining abilities of different ecotypes or strains. Among the crosses effected between the green varieties of different regions and the yellow mutant, Titabar green x yellow showed better combining ability with reference to average larval weight and filament length with 357% and 230% heterosis, respectively, over mid parent value. Crosses within the green varieties, however, resulted in negative heterosis. Similarly, no positive combining ability was noted in the crosses between yellow and hibernating strains.

Interspecific hybridization: The only two interspecific crosses of muga silkworms which have been tried thus far — *A. assamensis* x *A. mylitta* and reciprocal — showed hybrid inviability (71, 90). In *A. assamensis* x *A. mylitta* the oviposition was quite normal, but the eggs failed to hatch. The reciprocal cross resulted in extremely poor hatching, but the larvae could not survive.

27.3. Genetics

The muga fauna, despite limited heterogeneity, offer wide scope for genetic investigation, which has yet to be properly tapped. A preliminary study indicated that the total number of tubercles in *A. assamensis* is associated with sex. The larval body usually has 23 tubercles; however, about 6% of the larval population was observed to possess 18 to 19 tubercles, and these were invariably females. This character is suspected to be recessive because of infrequency.

27.4. Cytology

Cytological studies appear to have been made with muga silkworms. The chromosome number of *A. assamensis* Ww., as worked out through cytological studies, is n = 15 (35). The fifteen bivalents, though usually equidistant, exhibit an occasional tendency towards secondary association. They differ considerably in size. Some observations are also available on the chromosome number (n = 15) of the three muga varieties: green, wild hibernating and yellow mutant.

Chapter 28

REELING AND SPINNING

Muga can be reeled owing to its closed type of cocoon and continuous filament. The stifling of the cocoon is similar to that of tasar. The cocoons are cooked in a 0.5% alkaline solution (Na_2CO_3) for about 30 seconds and transferred to a reeling basin containing tepid water with a little soda. Normally the filament of 6 to 7 cocoons is fed onto the reeling appliance for warp and 10 to 12 for weft. Muga yarn is spun like tasar and eri.

28.1. Reeling appliances

Bhir: The bhir is a very simple reeling appliance consisting of a basin to serve as a water bath for the cocoons and a roller with a large wheel at one end for frapping. The filaments of cooked cocoons are joined by an operator (feeder) and passed into one hand of the reeler, who in turn feeds the thread onto a wooden roller (reel). The reeler rotates the roller intermittently and imparts twist by rubbing the yarn between his fingers before it is wound on the reel. The feeder and reeler face each other with the reeling apparatus between them. The process is actually one-end reeling by two persons.

About 500 cocoons are reeled per day to produce about 120–150 g of silk. The waste is nearly equal to the quantity of silk produced, and the reelability is about 50%. Re-reeling is also done on the same unit.

The pedalled Bhir is a slight improvement over the hand-operated model, as the reeler can use both hands for reeling, thereby ensuring a better quality of silk. But this appliance likewise engages two persons in one-end reeling, and hence production is limited (Figure 123).

FIGURE 123a. Bhir machine for muga reeling - hand operated

FIGURE 123b. Bhir machine for muga reeling - foot operated

Das-type muga reeling machine: This mechanical reeling machine requires only one operator. As it is foot operated, the reeler can use both hands for cocoon feeding and reeling. The reeled silk is wound on the bobbin, and a uniform rate of twist is imparted by the spindle and flyer. Nevertheless, because only one-end reeling is possible, the production is likewise limited.

Chowdhury-type reeling machine: This improved muga reeling appliance, designed on the principle of the tasar reeling-cum-twisting machine, is operated by two persons. It has four spindles, and the movement of the reeled yarn over the bobbin of this machine is very regular. Its output is about 1400x 4m per hour.

28.2. Muga fibre

The reelable filament length of muga cocoon is 500–800 m and the denier is about 5.5. The silk is highly lustrous and golden yellow or creamy white. After bleaching, it has a good affinity for dyes. Crystals of oxalate of lime are found in some quantity as an impurity. The ash content (2.06%) is almost equal to that of eri silk.

28.3. Microscopy of muga silk

Muga silk, like mulberry silk, is roughly elliptical in cross section. The two triangular brins, surrounded by sericin, normally face each other on the flat side. Striations are visible on the surface when muga silk is viewed longitudinally.

Part V

ERICULTURE

The name eri derives from the Assamese word "era", which means castor-oil plant, the main food of the silkworm. The history of eri culture is obscure, but it is believed to have originated in India.

Over 50 000 inhabitants of eastern India, particularly the northeastern states, practise eri culture as a subsidiary cottage industry. Various tribes of Mongolian or Tibeto-Burman origin (e.g., Meeches, Kacharis, Mikirs, Rabhas, Boros, Garos, Syntengs) are engaged in this industry. In contrast to the other non-mulberry silk industries, all operations from rearing to weaving are done mostly by the women. Apart from economic importance of eri for silk production, the pupae are also consumed by the tribes as food. Among the chief cocoon growing areas are North Cachar, Mikir Hills, Kamrup and eastern Goalpara in Assam; north Tripura; Muzaffarpur, Bhagalpur and Purnea in Bihar; Cooch Behar and Jalpaiguri in West Bengal; and West Manipur.

Reports on eri culture in Shantung and Che-King provinces of China are available. Steps are also being taken to establish it in New Guinea, on Formosa, in Madagascar, in Egypt and in other suitable areas. Attempts to introduce eri culture in America and in Europe have not been successful.

Chapter 29

MORPHOLOGY

Philosamia ricini Boisduval shares the basic characteristics of the Saturniidae, but because of its different generic origin (*P.* Grote) it has, as well, many characteristics which distinguish it from the species previously described. The differences reflected at each stage in the life cycle, from egg to adult, are discussed below.

29.1. Egg

The eggs are ovoid, candid white, measure 1.5 x 1.0 mm and weigh 6 mg (28). The pattern of follicular imprints (Figure 124) is very distinct from that of other species (95).

29.2. Larva

The larva on hatching is greenish yellow. It measures about 5 x 1 mm and weighs 1.5 mg. The body colour changes gradually to pure yellow by the end of the third day. From the third instar onward the body colour segregates into yellow, cream, green, blue or white. The fully mature larva, which measures about 7.0 x 1.5 cm and weighs 8 g, is translucent and covered with a white powdery substance. Both spotted and unspotted larvae are found. The spots are of various types: single, double, zebra and semi-zebra (Figure 125).

The prothoracic hood of the first-instar larva has a black dorsal band, which splits up into a pair of crescent-shaped markings in the second and third instars. These markings disappear at the fourth instar (Figure 126). The area about the antennae acquires a black dumb-bell-shaped mark in the fourth instar, which in the fifth instar splits into two oval dots.

FIGURE 124. Follicular imprints of *P. ricini*

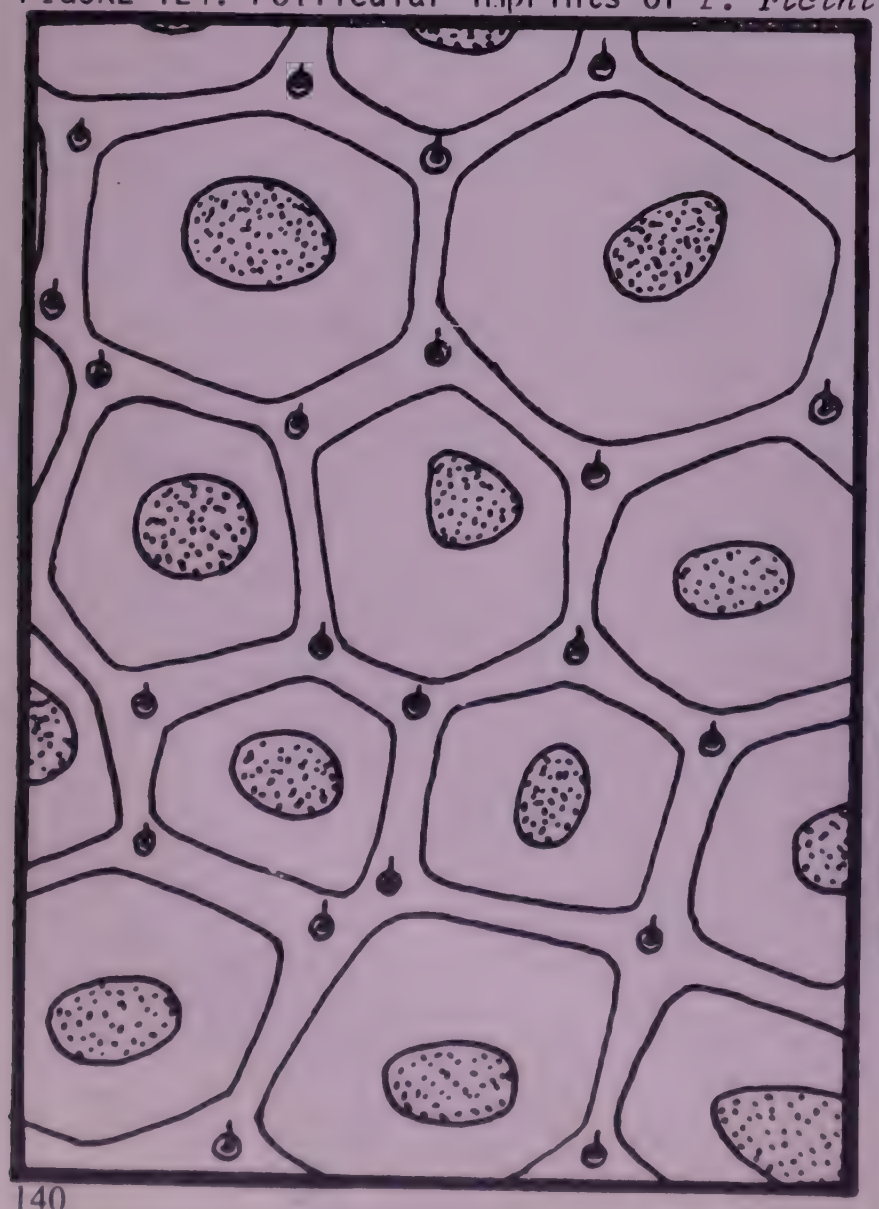


FIGURE 125. Plain and spotted larvae of *P. ricini*

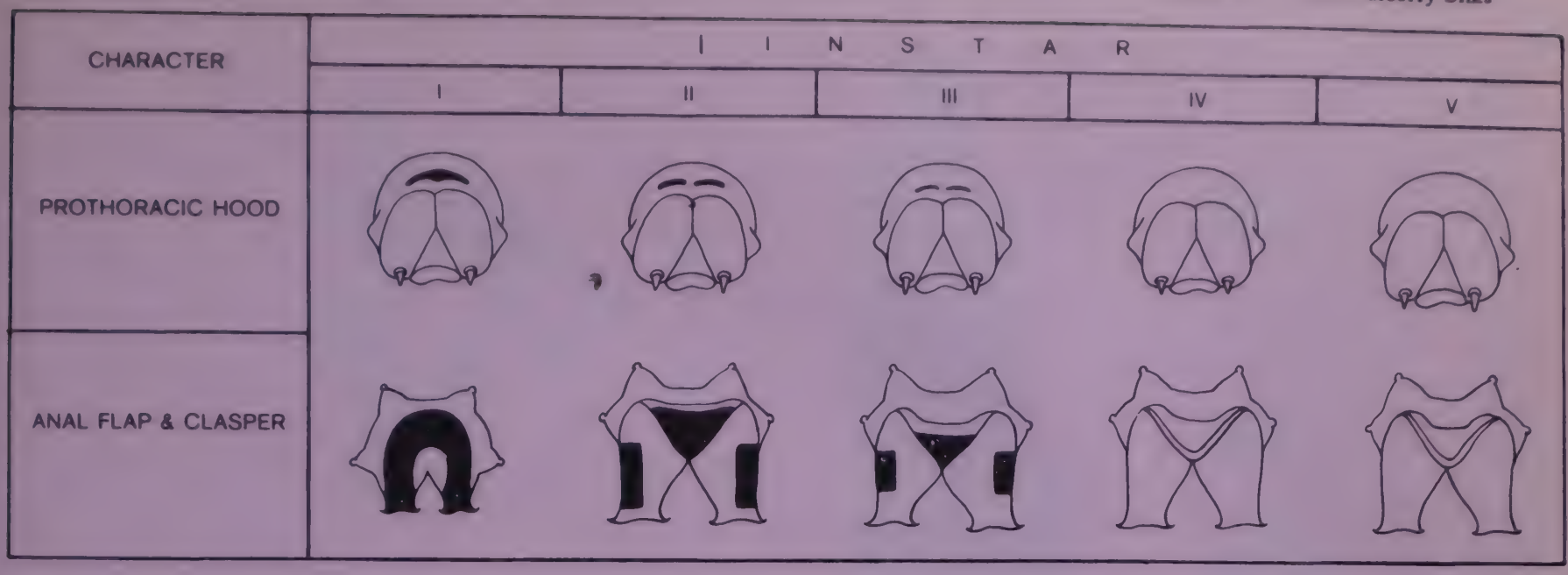


FIGURE 126. Developmental morphology of *P. ricini* larva:
(a) prothoracic hood; (b) anal flap and claspers

The planta, anal flap and claspers are light yellow throughout the larval span. The planta has a horizontal blue band at the top. Early in the first instar the markings on the anal flap and claspers are black and appear as a continuous band. In the second and third instars the black marks are triangular on the anal flap and rectangular on the clapsers (Figure 127). These marks disappear in the subsequent instars. The lateral line is creamy white and extends the length of the body.

The tubercles are very conspicuous and tubular in shape. They are bluish at the base and cream colour at the tip. The setae, which are pointed and blackish, number 180 at the third instar.

29.3. **Pupa**

The obtect adectious pupa does not depart from the basic Saturniidae pattern. It measures about 2.8 x 1.5 cm and weighs about 2.6 g.

29.4. **Cocoon**

The cocoons can be easily distinguished from those of *Antheraea*as they are elongated, soft, wooly, peduncleless, open mouthed and unreelable (Figure 128). They measure about 4.0 x 2.5 cm, weigh about 3 g and exhibit colour polymorphism, being brick red and creamy white. The shell weight and shell ratio are about 0.4 g and 13%.

FIGURE 127. *P. ricini* tubercle with setae

FIGURE 128. Cocoon of *P. ricini*

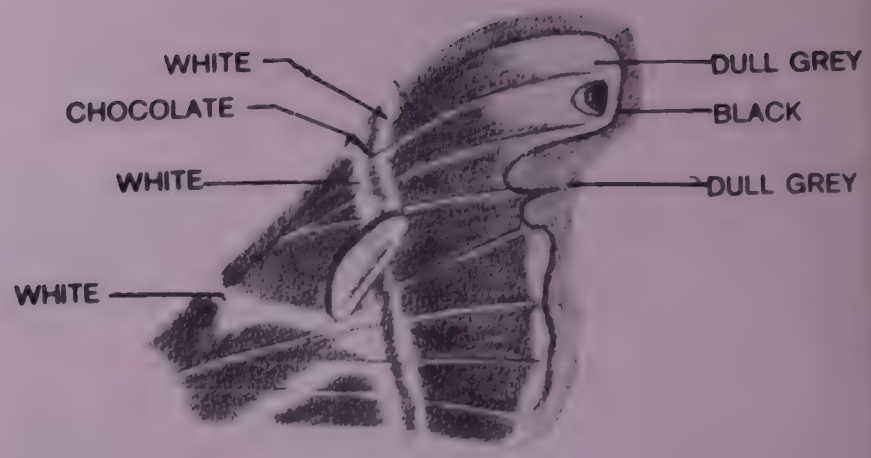


FIGURE 129. Fore wing of female *P. ricini*

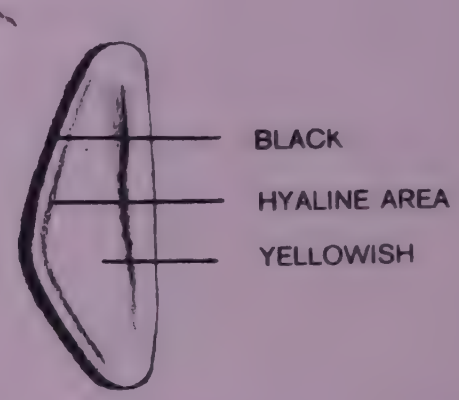


FIGURE 130. Ocellus of *P. ricini*

29.5. Moth

In length the male is about 2.5 cm and the female 3.0 cm. The average wing expanse of male and female moths is 13 cm and 15 cm.

Fore wing: The fore wing of both sexes is more or less similar in structure and colour pattern. The ground colour is either brownish, blackish or chocolate. The fore wing is about 1 242 mm^2 in males and 1,465mm^2 in females.The characteristic antemedian line (AM) is bright chocolate coloured with a white border on either side and almost runs through the centre (Figure 129). The postmedian line (PM) is black with a single dull grey border on either side. The ocellus in both the sexes is crescent shaped. A conspicuous black spot, the pterostigma, with a whitish tinge is present at the top of the wing apex. In addition, the wing has a few white oblique lines.

Hind wing: The hind wing measures about 890 mm^2 in males and 1 037 mm^2 in females. The black PM, unlike that of the fore wing, is split in two. The AM and ground colour are similar to those of fore wing.

Ocellus :The shape of the ocellus is characteristic of the insect. The hyaline area (HA), almost invisible, is located in the most anterior region of the ocellus. The area of the ocellus in the fore and hind wings is about 36 mm^2 and 30 mm^2 in the male and 40 mm^2 and 35 mm^2 in the female. The HA of the fore and hind wings is 10 mm^2 and 8 mm^2 in the male and 12 mm^2 and 10 mm^2 in the female. The colour pattern is identical, however, in both sexes (Figure 130).

The scales are generally triangular with one to four spines at the top, although long bristelike scales with pointed ends are also found. As for wing venation, the wavy median cross vein (Mc) joins both A_1 and A_2 The anal veins An_2 and An_3 are fused in the fore wing.

Chapter 30

FOOD PLANTS

The eri silkworm feeds mainly on *Ricinus communis*. (bharenda or castor-oil plant). The important secondary food plants are *Heteropanax fragrans* Seem. (kesseru), *Manihot utilissima* Phol. (simul-alu), *Carica papaya* L. (papita), *Evodia fraxinifolia* Hook.f.(pyam) and *Ailanthus excelsa* Roxb. (maharukh). Other secondary food plants reported are *Jatropa curcas* L. (bhotera), *Sapium* spp. P.Br. and *Plumeria rubra* L. (forma). *acutifolia* Poir. (gulchin).

30.1. Distribution

R. communis is grown in many parts of the world, including Sudan, Egypt, India, Burma, Sri Lanka, Malaysia, Philippines, Indonesia, Brazil, the U.S.A. and Mexico. Widely distributed in India, it is used mainly for ericulture in Assam, Tripura, West Bengal, Bihar, Meghalaya, Arunachal Pradesh and Manipur, where it is grown as a self-generating crop on hillsides, bunds and other wasteland.

30.2. Taxonomy

The taxonomy of *R. communis* (51, 56, 105) has been described as follows:

Order: Euphorbiales; Family: Euphorbiaceae
Habit: evergreen shrub, annual, biennial or perennial.
Leaf : simple, alternate.
Inflorescence: terminal raceme.
Flower: small, incomplete, unisexual, monoecious, upper female and lower male, actinomorphic, hypogynous; perianth in three to five whorls, united (Figure 131); male flower, manystamens, polyadelphous; female flower – carpels three, united; ovary, three-lobed, three-celled with one ovule in each cell; styles – three bifid, long or short, six stigma.
Fruit: globose capsule, generally echinate.
Seed: albuminous.

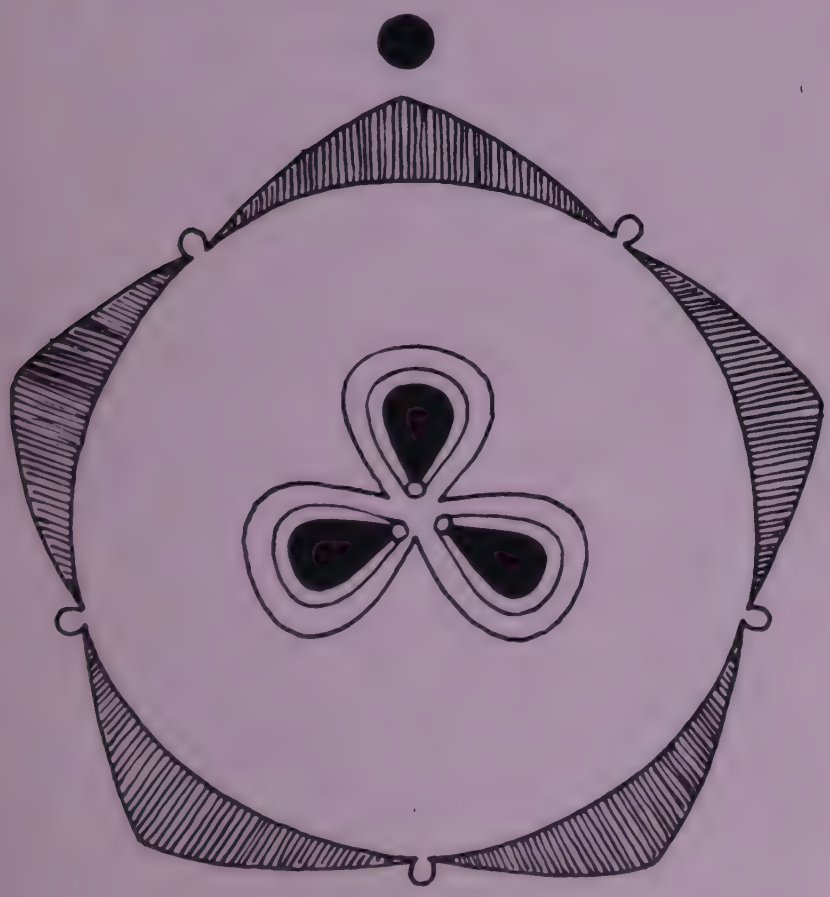


FIGURE 131. Floral diagrams of *R. communis* L.: (a) female; (b) male

Table 34. Controls against the important pests and diseases of *R communis* and control measures

Pests/diseases	Identification	Control measures
Castor semilooper (*Achaea janata*)	Grey looping defoliator	Endrin (0.3%) spray at 1 100–1 700 litres/ha. Collection and destruction of larvae.
Castor seed borer (*Dichrocrocis punctiferalis*)	Reddish brown seeds/pods borer.	Infested parts burnt followed by dusting with BHC (5%) at 70–100 kg/ha. Endrin (0.3%) spray.
Hairy catepillar (*Euproctis lunata*)	Reddish defoliator	BHC (5%) dust at 75–100 kg/ha Collection and destruction of larvae/eggs.
Castor butterfly *(Erogolis merione)*	Green spiny defoliator	0.2% BHC/DDT or 0.3% endrin spray at 1 100–1 800 litre/ha.
Seedling blight (*Phytophthora parasitica*)	Dull green patch on both surfaces of cotyledonary leaves.	Low-lying areas should be avoided for sowing. Bordeaux mixture spray.
Alternaria blight (*Alternaria ricini*)	Dull brown spots on cotyledons/leaves with concentric rings. Inflorescence and capsules covered with sooty growth.	Seed treatment with Agrosan G.N. Ceresan, etc. in the initial phase of the disease.
Rust (*Melampsora ricini*)	Tiny pink pustule on the under surface of the leaves, followed by development of yellow spots on the upper surface.	sulphur dusting at 10–12 kg/ha.
Powdery mildew (*Leveillula taurica*)	Colourless shiny patches appear on the under surface of the leaves, turning the upper surface pale brown.	Same as above.
Leaf spot (*Cercospora ricinella*)	Tiny black or brown spots with pale green margins on both surfaces of leaves, turning pale brown and then greyish with blackish structures at the centre with dark brown margins.	Growing resistant varieties. Blitox (0.3%) spray.

30.3. Climate and soil

The castor-oil plant can be cultivated in diverse climates and on poor sandy to rich alluvial soils. In humid tracts it becomes excessively luxuriant and assumes a perennial nature. The castor-oil plant can withstand drought and slightly acidic soil conditions, but not soil alkalinity and waterlogging. Heavy black cotton soils with a clay content of 80–90% are unsuitable.

30.4. Cultivation

R.communis is propagated through seeds, which are sown mostly in June and July. The land is ploughed two or three times, followed by harrowing and planking. The seeds are sown 6 to 10 kg/ha in rows 50 to 90 cm apart either by dibbling or in furrows. After about ten days the crop is thinned to maintain 60 to 90 cm of space between the plants in each row. One or two hoeings with weeding and occasional earthings-up are desirable. The crop is seldom manured, but sheep penning or green manuring with a leguminous crop is occasionally applied. When rainfed, the yield per hectar is about 14 metric tons.

30.5. Genetics and breeding

In *R.communis*such characteristics as stem colour, gland colour and leaf lacination are monogenic (52, 153). In a cross between spiny and spineless fruits, incomplete dominance was obtained (153). Breeders have tried to combine several desirable characters for high yielding ability in terms of seed, but no noteworthy effort has been made to improve leaf quality and productivity for eri culture.

30.6. Cytology

The somatic number of *R. communis* is reported to be 20 (61). The plant is a secondary balanced polyploid (159). The occurence of secondry associations between two pairs of bivalents at metaphase has also been confirmed (111).

30.7. Plant protection

The major insect pests and diseases of *R. communis* and controls against them are listed in Table 34.

Chapter 31

GRAINAGE

The eri grainage operations differ considerably from those of tasar and muga. The domesticated nature of the eri silkworm makes grainage quite systematic and easy to control.

31.1. Selection and storage of seed cocoons

The criteria for seed cocoon selection is virtually the same as for tasar. The seed stock does not require prolonged preservation because of the polyvoltine nature of eri. In case of a scarcity of food plants the pupae can be forced to hibernate by subjecting them to gradually lower temperatures down to 5°C.

The seed cocoons are stored by spreading them thinly on circular split-bamboo trays on wooden racks (135). Normally the seed cocoons are preserved at room temperature and humidity, preferably at 22-24°C and 70-80% R.H. Traditional rearers store seed cocoons inearthen pots or on split-bamboo mats, which are placed near the fire during the winter.

31.2. Emergence

Depending on climate, the period from cocoon formation to moth emergence ranges from 13 to 18 days. Emergence, which continues for 3-5 days, starts at 3:00-5:00 in the morning and may continue until 16:00-17:00 hours with maximum emergence in the hours 3:00 to 9:00. It takes place under natural light at room temperature and humidity. Unlike the tasar and muga moths, eri moths take no more than 5 to 8 minutes to emerge as the cocoons have an open end. Soon after emergence they emit a creamy excreta which dirties the cocoon shell. Within 45 minutes to an hour they become fully active and prepare for mating.

31.3. Coupling

The freshly emerged healthy female moths are collected in the morning and tied to kharikas with cotton thread 8 to 10 cm long. Deformed and crumpled females are not selected for coupling. The kharikas — identical to those described under muga grainage (Figure 118) — are hung on strands of wire stretched across the room 60-90 cm above the floor. Either the male moths are positioned by hand or they themselves approach the virgin female moths.

Eri moths have very good coupling aptitude. Maximum pairing takes place at 16:00 to 18:00 hours and the moths may remain coupled for 24 hours, although 3 to 6 hours are adequate. The male moths can be utilized for a second coupling. The response to hand coupling is also encouraging.

Above all, the overcrowding of moths should be avoided and grainage room should be properly ventilated to allow the sex pheromone of the females to act effectively.

Cages of wire mesh on wooden frames are used for selective breeding (Figure 132). The seed cocoons are stored inside the cage, and small kharikas are used for coupling.

31.4. Egg laying

The decoupled fertilized females are left on the kharika. Egg laying starts 1 to 2 hours after decoupling and continues for 3 to 4 days, but only the eggs laid on the first two days are considered for rearing. On the average, each moth lays 450-500 eggs, most of them on the first day. The eggs are deposited in a single layer at two or three places on the kharika. Specially designed egg carriers are used for distribution of the laying (Figure 133).

For a stable and better crop it is desirable to use the cellular method of mother moth examination followed by disinfection of the eggs in 5% formalin for five minutes.

31.5. Hatching

The disease-free layings are incubated either individually or collectively in the grainage house at normal room temperature and relative humidity, preferably at 22–24°C (particularly during the winter) and 75–80% R.H. Hatching starts at 6:00 to 9:00 in the morning within 9 to 10 days in sumer and 14 to 15 days in winter.

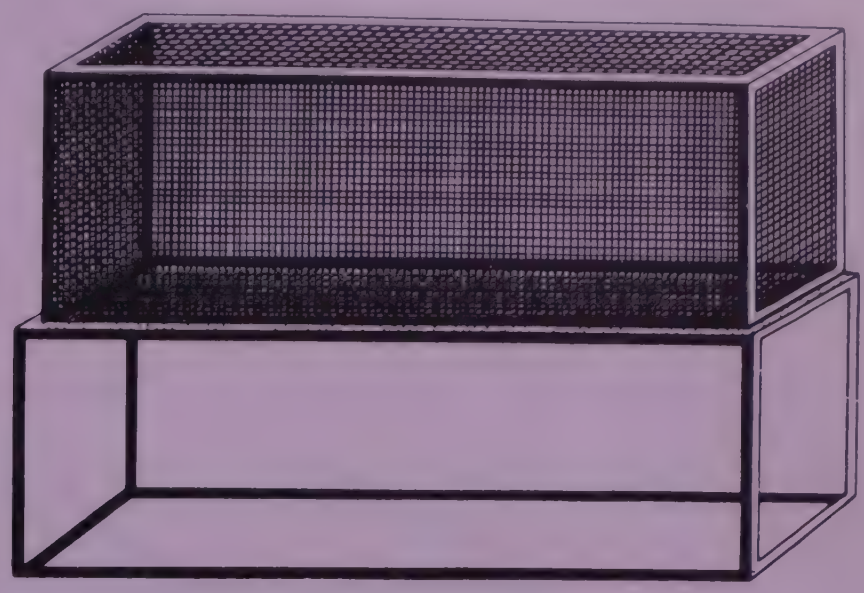


FIGURE 132. Breeding cage

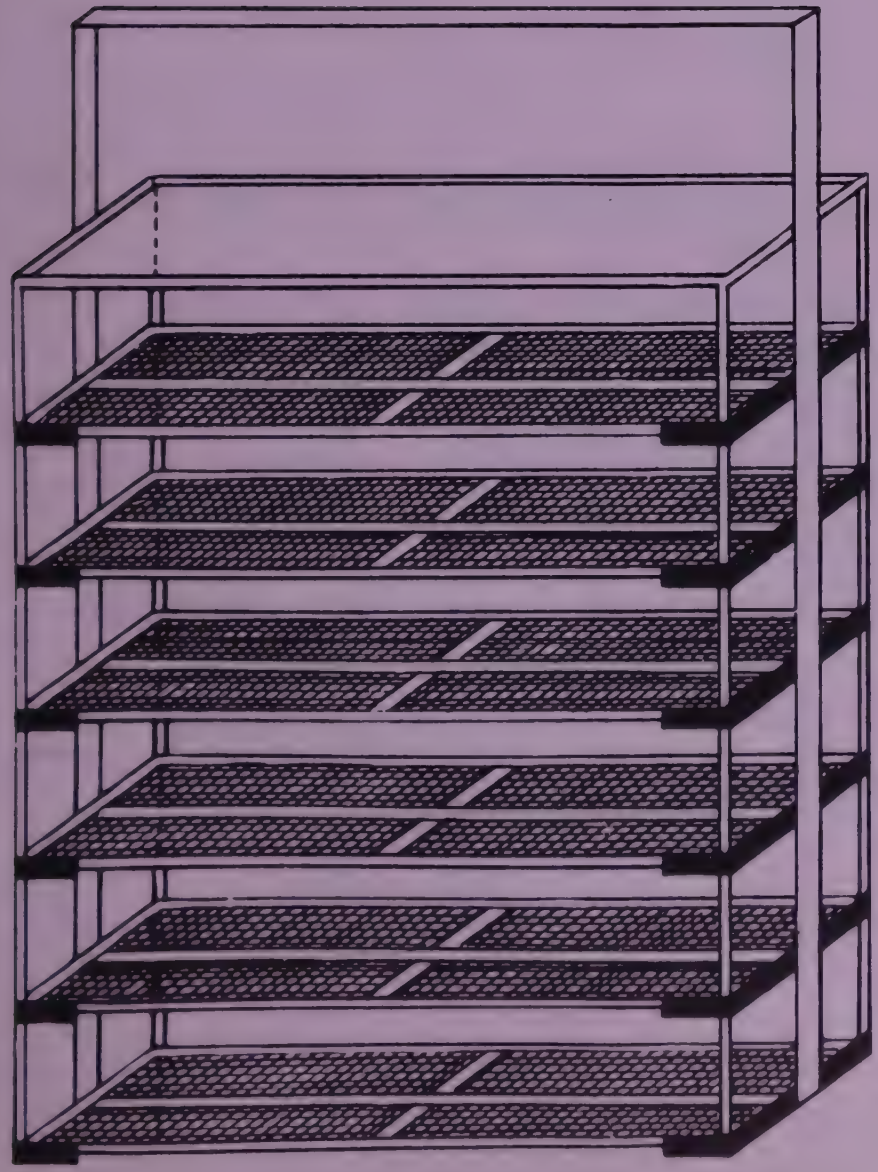


FIGURE 133. Egg carrier for eri layings

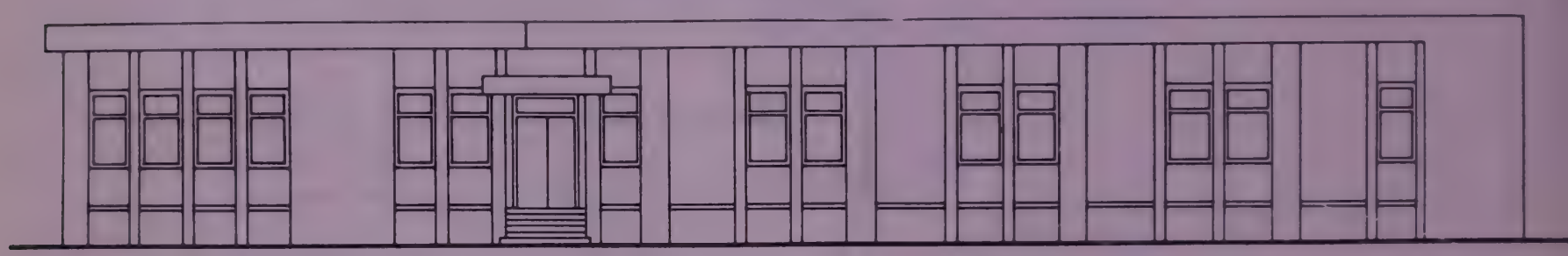
Chapter 32

REARING

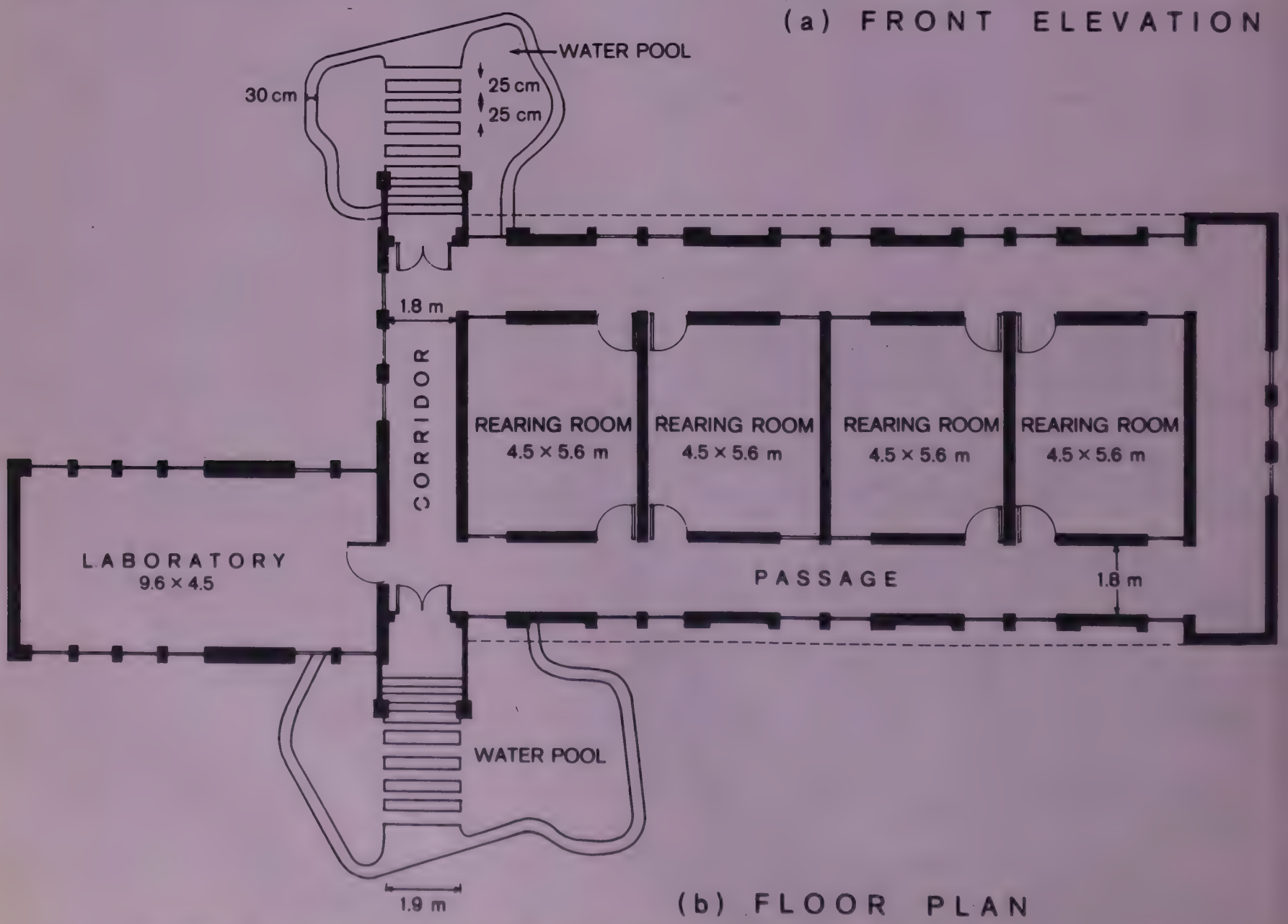
Rearing the larval population of *P. ricini* is entirely different from that of *Antheraea* silkworms. Neither the provision of foliage suitable or each larval stage nor the protection of larvae from attack by its enemies and from natural calamities is difficult.

32.1. Rearing house

The rearing house should be ideally located and protected against rats. It should have verandah on all the four sides (Figure 134) and an adequate number of doors, windows and ventilators to ensure cross circulation of air and good light. Glass panes on the outside wire-mesh fitted panels on the inside effectively prevent the access of various pests and parasites. Naturally, the size of the rearing house is adjusted to the rearing capacity.



(a) FRONT ELEVATION



(b) FLOOR PLAN

FIGURE 134. Rearing house for eri culture: (a) front elevation; (b) floor plan

32.2. **Rearing appliances**

The important appliances are rearing racks, trays and chandrika (cocoonage). The wood or bamboo racks (Figure 135) are about 1.8 m high, 2.1 m long and 60 cm deep with six shelves spaced 25 cm apart. The feet of the rack rest on antwells. The rearing trays, made of split bamboo and preferably circular, should have a diameter of nearly 90 cm so that two trays can easily be accommodated on one shelf.

FIGURE 135. Rearing rack

The chandrika is made of split-bamboo tape (called "chandrika phool") about 6 cm wide with big triangular holes to allow larval movement. The tape is fixed on a rectangular or circular bamboo mat (like a rearing tray) in the form of spirals, maintaining a distance of about 4 to 5 cm between spirals.

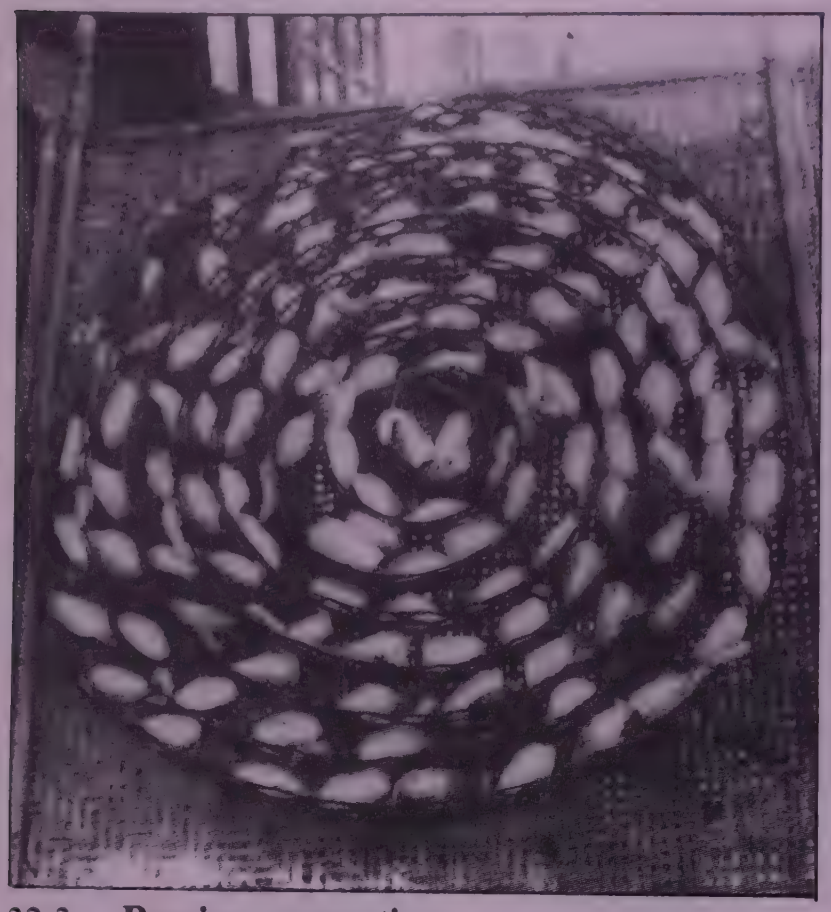


FIGURE 136. Chandrika for cocooning

32.3. Rearing preparation

The volume of rearing to be undertaken should be established according to the availability of foliage. An average of about one metric ton of foliage is required for the rearing of 100–125 laying from hatching to ripening.

All rearing appliances and rooms are thoroughly cleaned and disinfected two or three days in advance. The chandrika is subjected to a low flame in order to remove any adhering silk filaments. The rearing room should be made as airtight as possible before spraying the disinfectant and kept closed for 15 to 20 hours afterwards.

32.4. Larval behaviour

Eri silkworms are reared in both the plains (West Bengal, Bihar, etc.) and the hills (up to 1 500 m above sea level in Assam, Meghalaya, etc.) at temperatures ranging from 15°C in winter to 35°C in sumer and from 50% to 100% relative humidity; however, the optimum range of temperature and relative humidity is 24–26°C and 75–85%. The larval span varies from 20 days in summer to 50 days in winter.

Unlike other non-mulberry varieties, eri silkworms do not eat the empty eggshell on hatching nor the cast-off skin after moulting. Furthermore, like *A. mylitta* they do not consume the midrib and petiole. They have a very poor gripping power. The mature larvae produce a rustling sound when rolled between the fingers and have a tendency to move upward and away from the foliage.

The mature larvae search a suitable cocooning place on the chandrika and remain there 4 to 5 hours after discharging the last excreta. First the base of the cocoon is formed by moving the head to trace a horizontal figure eight. This is followed by the formation of sides and finally the upper part, but during these operations the head movement is irregular. After about 13 to 15 hours of spinning the larvae are invisible. The cocooning is completed in three days during the summer and in five days during the winter. Unlike silkworms of the *Antheraea* species, eri silkworms do not form a ring and peduncle, and because the cocoons are open at one end, the filament is discontinuous.

The newly hatched larvae of *P. ricini* measure about 4 × 0.7 mm and weigh about 1.3 mg. The mature larvae are about 8.5 cm long and 1.7 cm wide and weigh about 6.2 g, exhibiting an increase of 21, 24 and 4 770 times respectively.

32.5. Rearing techniques

The eggs are kept in the rearing tray on a piece of paper for 24 hours before hatching. They are covered with a few tender top leaves when they start to hatch. The larvae crawl gradually onto the underside of the leaves and remain very close together in groups. It is advisable to feed them chopped leaves until the first moult, as they may become enclosed in the dried leaves and discarded at the time of cleaning.

Extreme care is taken to ensure that the age of the leaves is compatible with the growth stage of the larvae. They should not be fed wet, dirty, diseased, dried or ripe yellow leaves, or offered too many leaves at a time. The plucked leaves are loosely heaped and kept covered with wet gunny cloth. The density of the larval population should be properly regulated. Each larva requires, on the average, about three times the space occupied by its body throughout the larval span.

The larvae are fed on trays or on hanging leaf bundles. If fed on trays, whole or chopped leaves are spread over the larvae. Considerable time is saved, but the rearing bed becomes dirty with excreta. In any case, this method is necessary until the second moult. If the hanging-bundle method is used, eight to ten leaves are tied together and hung on a stick resting across the two parallel bars of the stand. The vertical position of leaf lamina not only facilitates almost complete consumption of the foliage, but also permits the litters to drop directly onto the tray underneath without soiling the leaves. This feeding method thus combines foliage economy and cleanliness.

Up to the third instar the larvae are given four feedings a day, and the late instars fed five times a day at regular intervals. The first feeding must be served at 5:00–6:00 and the last at 21:00–22:00 hours. Moulting larvae, however, are served only when about 85% of them have cast off their old skin.

The rearing bed should always be cleaned before noon, else the excreta star decomposing with the rise in temperature. Not only the litters, but also the midribs, petioles, dry and unconsumed leaves as well as other waste must be removed. While cleaning, fresh leaves are put on the rearing tray to attract the larvae. Dead and infected larvae are removed as soon as they are noticed. When the batches are preparing to moult, cleaning should be conducted before they settle.

It is desirable to rear early — and late-instar larvae in separate rooms because of their substantially different requirements. The rearing is generally conducted under normal room conditions in all seasons, but in case of necessity the temperature and relative humidity of the rearing room can be brought to the desirable level by artifical means. As soon as the larvae mature they are placed in the chandrika for spinning.

The quality of the cocoons greatly depends on the food plant. The various eri food plants, in order of efficacy, are castor-oil payam, kesseru and tapioca. As to the seasonal effect, the cocoons produced in late spring and in late autumn are the best.

32.6 Economics of rearing

Compared with the other non-mulberry silkworms, eri yields a very rich harvest. Apart from the benefits of indoor rearing, the silkworm itself is extremely hardy and less susceptible to diseases. With feeding on the castor oil plant, it is possible to obtain a 75–85% effective yield. The cost of production, however, is quite high owing to the indoor rearing, the raising and maintenance of the food plants and other contributing factors. Moreover, the returns are very low because the cocoons are unreelable.

Chapter 33

DISEASES AND PESTS

33.1 Diseases

The eri silkworm is less susceptible to diseases than other non-mulberry varieties, Whereas pebrine (microsporidiosis), flacherie (bacteriosis) and muscardine (mycosis) are common in eri silkworms, virosis is virtualy absent.

Flacherie The first apparant symptom is loss of appetite (28). The infected larvae becomes soft and the body colour changes. It vomits and excretes a semisoild excrement. After death the worm putrefies and emits a repellent odour.

Flacherie is caused by an ultravirus infection followed by a bacterial attack (28). It is transmitted orally through contaminated food material. The disease accounts for the greatest loss (14 to 30%) in eri culture. The minimum loss is observed in January March and the maximum in April-June.

Pebrine The symptoms are similar to those in *A. mylitta* The contention that *Nosema* bombycis is the causative agent has been contradicted (58); rather, another microsporidian of the genus *Nosema* is responsible for the infection (187, 188). The spore is 3.2–4.6 microns in length and 1.5–2.1 microns in width.

Transmission is both transovarial and oral. The incidence of microsporidiosis is sporadic, but the infected worms contaminate the whole brood.

Muscardine: The infected worm loses flexibility and becomes brittle and compressed (28). The corpose of the worm is mummified and covered with a white encrustation, which later turns green.

Botrytis densa has been identified as one of the fungi responsible for muscardine (102). The route of infection is the integument, especially the thinner intersegmental areas. The crop loss due to this disease is negligible.

P. ricini is immune to grasserie (28), but the disease has been reported in its wild counterpart, *P. cynthia.* It is easily recongnizable because of the characteristically swollen body. The body changes colour and the larva moves restlessly. In the advanced stage of infection the skin becomes fragile and the blood turbid.

Both cytoplasmic and nuclear polyhedrosis viruses have been cited as the causative agents (15, 182). Though grasserie is not found in *P. ricini*, nuclear polyhedral inclusion bodies (PIB) have been detected (15); hence, *P. ricini* is considered a healthy carrier of the virus (197).

An interesting case of the maternal inheritance of grasserie resistance has been reported in the hybrids of *P. ricini* and *P. cynthia* (103). In the cross *P. ricini* x *P. cynthia* that F_1's were, like *P. ricini*, perfectly resistant to grasserie. Conversely, in the reciprocal cross the F_1's were, like *P. cynthia* highly susceptible. At F_2 some of the larvae succumbed to grasserie, while others exhibited resistance.

33.2. Pests

Because of the domesticated nature of *P. ricini*, the loss due to pests is comparatively small. Among the insect enemies, the tachinid fly *Tricholyga bombycis* is the only serious paraiste. The biology, life cycle (31, 186) and mode of infection are fairly comparable to those of *B. zebina*

33.3 Controls

As flacherie is attributable mainly to starvation and malnutrition, the worms should be fed with leaves of suitable quality. Heavily manured leaves or mixed food from different plants should not be used.

Mechanical control is the only practical precaution against *T. bombycis* Infestation can be avoided by preventing the entry of the flies into the rearing room.

Chapter 34
BREEDING AND GENETICS

The earlier investigations of *P. ricini* were directed mainly toward genetics and cytology; however, the recent studies have given some stress to the breeding aspects of this insect. As the eri fauna is highly heterozygous, breeders therefore resort to pure line selection and hybridization.

34.1 Breeding

Pure line breeding: Twenty-three lines have been fixed from the *P. ricini* populations of different regions. In addition, six pure lines have been pooled from the progenies of *P. cynthia* x *P. ricini* The physical marks considered for purification are larval body colour, larval spotting pattern and cocoon colour.

Hybridization: The combining ability of five pure lines of *P. cynthia* x *P. ricini* were tested with a Nongpoh (Assam) line. Whereas the hybrid lines were Ww, Wlr, Gw, Glr and Gdr (W, G = white, green larva; w, lr, dr = white, light red, deep red cocoon), the Nongpoh line was WP (W, P = white, plain larva). Of the twelve cross combinations, WP x Gw resulted in about an 80% gain over mid-parent value for hatching percentage, larval weight, cocoon weight, shell weight and shell ratio. This was followed by Ww x Wp with a heterosis index of about 60%.

Interracial hybridization has been practised extensively (30). The resulting bybrids have been named as follows: *ricini x cynthia* = *wallacei* Tutt., *cynthia x ricini* = *russeli* Wts., *advena x canningii* = *andrei* Wts., *canningii x advena* = *lastoursi* Wts., *canningii x cynthia* = *xanthroxylon* Wts., *pryeri x ricini* = *rothschildi* Wts, *advena x ricini* = *vesta* Wts., *ricini x vesta* = *balli* Wts., *pryeri x vesta* = *lefroyi* Wts., *pryeri x advena* = *oberthuri* Wts., *advena x pryeri* = *pryadvena* Wts. and *canningii x obscura* = *reversa* Crotch. The cross *walkeri x pryeri* has also been mentioned (115). There is practically no information regarding the breeding aspects of these hybrids except for the little given above for *P. cynthia x P. ricini.*

34.2 Genetics

Inheritable traits: Philosamia is an interesting genus from the view point of genetics. Some of the prominent inheritable characteristics of two important members, *P. ricini* and *P. cynthia* are given in Table 35.

Inheritance in *P. ricini*: Studies on the inheritance of larval body colour (135), spotting pattern and cocoon colour (28) have shown that all these characteristics are monogenic. The blue larva is dominant over the yellow, the zebra over the double spotted and plain, the double spotted over the plain and the brick red cocoon over the white. No link whatsoever is observed between body colours and spotting patterns.

Inheritance in hybrids

P. ricini x *P. cynthia* : A remarkable degree of maternal inheritance has been observed in *P. ricini* x *P. cynthia* at the F_1 level (28, 103). The hybrid larvae from the *P. cynthia* mother are smaller, are susceptible to grasserie and have a longer larval span. The reverse is true in the reciprocal cross.

The cocoons from both crosses are intermediate in such characteristics as coloration, shape, volume and flossiness. The prominent peduncle (*P. cynthia*) appears in a rudimentary form in the offspring of the *P. cynthia* mother.

In *P. ricini* (white larva) x *P. cynthia* (green larva) at F_1 only green larvae appeared, but at F_2 the larvae were segregated into white, green, yellow and blue. It has been suggested that the green colour is controlled by the "yellow" and "blue" genes. The presence of a yellow inhibitor factor is also assumed between yellow and white (28).

Canningii x Obscura: A new form has been evolved from *canningii x obscura* (30). In the first generation some larvae had heavy lateral markings, such as black bars rather than slightly oval dots on the posterior segments. The resulting moths favoured the ground colour of *obscura* but maintained the vivid pink

Table 35. Heterogeneity in the qualitative characteristics of *Philosamia*

Characteristics	*P. ricini*	*P. cynthia*
Egg		
Shell colour	White	Cream
Yolk colour	Cream	Cream, green
Larva		
Thorn	Weak	Prominent
Body colour	Yellow, green, blue cream, white	Green
Spotting pattern	Single, double, semi-zebra, zebra	Single, double
Size	Bigger	Smaller
Span	Shorter	Longer
Moth colour	Chocolate	Chocolate with greenish tinge
Cocoon		
Structure	Flossy and peduncleless	Compact and pedunculate
Colour	White, brick red	Cream, chocolate
Voltinism	Multivoltine	Unibivoltine
Resistance	Resistant to grasserie	Susceptible to grasserie.

border of the *canningii* median line, which is absent in *obscura*. They showed as well, a complete reversal of tone on the opposite sides of the median line - that is, the ground colour near the body was darker than that on the other side of the median and nearer to the margins. The race was consequently named *reversa* Crotch. Some of the *reversa* x *reversa* offspring did not have the bright median and were thus *obversa* The cross *reversa* x *advena* established a race generally disignated *adversa*.

34.3 Cytology

P. cynthia possess 13 haploid chromosomes, whereas *P. ricini* has 14 (115). It is therefore supposed that *P. ricini* derives from *P. cynthia* through the breakage of chromosomes (28). The haploid numbers of *walkeri* and *pryeri* are likewise 13 and 14, respectively (115).

Interesting cytological observations have been made with reference to hybridization (28). Whereas the chromosome number of *walkeri* from Manchuria (M) and Korea (C) is 13, that of *pryeri* from Kyushu (K) and *P. ricini* from Formosa (F) is 14. The chromosome number and pairing behaviour of different crosses observed at metaphase I are as follows:

C X M	n = 13	(all bivalents)
C X K, C x F, F x F, M x F	n = 13	(12 bivalents + 1 trivalent)
K X M	n = 12	(10 bivalents + 2 trivalents)

These observations have suggested the fragmentation of one of the chromosomes. Besides, in the races M and K there was a reciprocal translocation between the nonhomologous chromosomes.

Chapter 35

BIOCHEMISTRY

Extensive biochemical studies have been made on *P. ricini*, particularly for the purpose of devising synthetic diets based on the utilization of proteins, amino acids, carbohydrates, vitamins, lipids and essential organic and inorganic dietary elements.

35.1 Artificial diets and constituents

Numerous chemically refined diets have been synthesized; however, the rearing performances are most satisfactory with the two diets (44) presented in Table 36.

35.2 Utilization of constituents

Vitamins: Of the eleven water-soluble vitamins, those which contribute significantly to eri silkworm growth and development are pyridoxal, riboflavin, thiamin, ascorbic acid and folic acid. The absence of biotin, nicotinic-acid, p-amino benzoic acid, pantothenic acid, inositol and choline has no adverse effect.

Carbohydrates: Only eighteen of twenty-six carbohydrates constituents are utilized by the eri silkworm (121) as shown in Table 37.

Table 36 Composition of two chemically refined diets for *P. ricini*

Constituents	Quantities	
	Diet A	Diet B
6-Fürfurylamino purin	54 mg	–
Agar-agar	1.5 g	1.5 g
Soybean powder	2.5 g	2.5 g
Casein	1.3 g	1.3 g
Sugar	1.0 g	1.0 g
B -sitosterol	0.1 g	0.1 g
Wesson's salt mixture	0.3 g	0.3 g
Dry brewer's yeast	1.0 g	1.0 g
Vitamin mixture II	31 mg	–
Cholin chloride	5.5 mg	
Ascorbic acid	25 mg	25 mg
Cellulose powder	1.2 g	4.1 g
Sorbic acid	0.1 g	0.1 g
Water	27 ml	27 ml

Table 37. Carbohydrates requirements of *P. ricini*

Carbohydrates	Constituents tested	Constituents utilized
Monosaccharides:		
Pentose	Ribose, xylose arabinose, rhamnose	Only xylose
Hexose	Sorbose, glucose, fructose, mannose, galactose	All but sorbose
Disaccharides	Sucrose, maltose, trehalose, cellobiose melibiose, lactose	All
Trisaccharides	Raffinose, melexitose	Both
Polysaccharides	Starch, dextrin, glycogen, inulin	All but inulin
Sugar alcohols	Sorbitol, mannitol inositol	All but mannitol
Glycosides	∝ methyl glycoside, ∝ methyl mannoside	Neither

The total carbohydrate content decreases during embryonic development. Figure 137 shows the variation during the larval and pupal stages (149, 151).

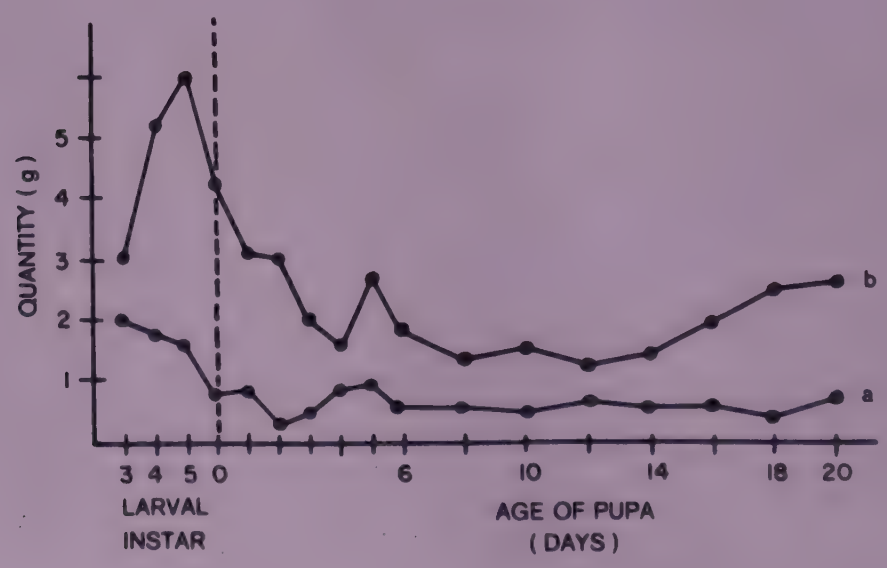


FIGURE 137. (a) Glucose and (b) glycogen in the *P. ricini* fat body during larval-pupal development in g/100g dry tissue weight

Nitrogen: The total nitrogen content of the egg remains constant throughout development (144, 145). In pupal tissues the nitrogen metabolizes with a very moderate amount of overall degradation. The protein variation is large in the beginning and small at the end (Figure 138).

Free amino acids: For survival the eri silkworm requires ten amino acids: arginine, histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan and valine (119).

The egg, pupa and larva have seventeen common amino acids: α-alanine, arginine, glycine, glutamic acid, leucine/isoleucine, methionine sulphoxide, proline, serine, byrosine, valine, histidine, tryptophan, threonine, glutamine, α-amino isobutyric acid, lysine and phenylalanine. Besides, the egg has aspartic acid and cysteic acid, and the larva and pupa contain citrulline, cystine, methionine, aspargin, β-alanine, homoarginine and hydroxyproline (147).

Phosphoruscompound: The average total phosphorous (TP) content of the egg (0.58 mg/100 mg egg) remains almost constant throughout embryogenesis (143). In the pupa, as well, the TP level remains constant during metamorphosis, with an average value of 1% of the dry tissue weight (150).

Enzyme activities

Phosphates: In *P. ricini*, acid phosphatase tends to prevail over alkaline phosphoatase during all stages of the life cycle other than larval period (146).

Proteolytic and amylolytic activity: During larval development the eri silkworm manifests a notable increase in proteolytic activity up to the second instar (149), followed by a sharp decline to a minimum level in the final instar (Figure 139). The amino-acid-rich leaves of the castor-oil plant seem to be responsible for the low proteolytic activity during the last instar, when the insect consumes large quantities of food. The proteolytic activity decreases during larval-pupal transformation and increases slowly from the tenth day of pupation until emergence.

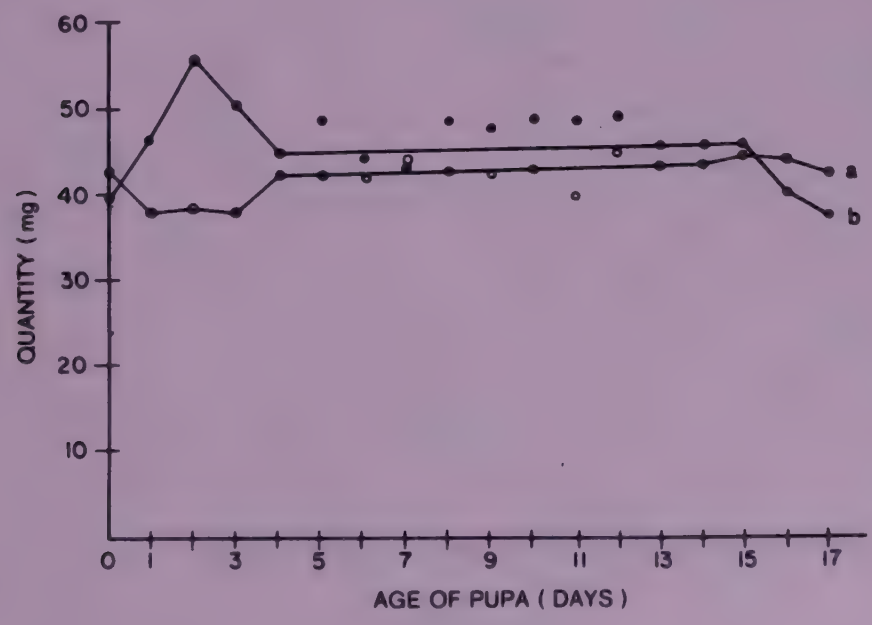


FIGURE 138. Nitrogenous constituents in *P. ricini* pupal tissues during metamorphosis (a) mg nitrogen/pupa; (b) mg protein/100 g dry tissue weight

The amylolytic activity follows an ascending trend until cocoon formation (Figure 140). The level of activity also depends on the type and quantity of food ingested as well as on the utilization of polysaccharides (129).

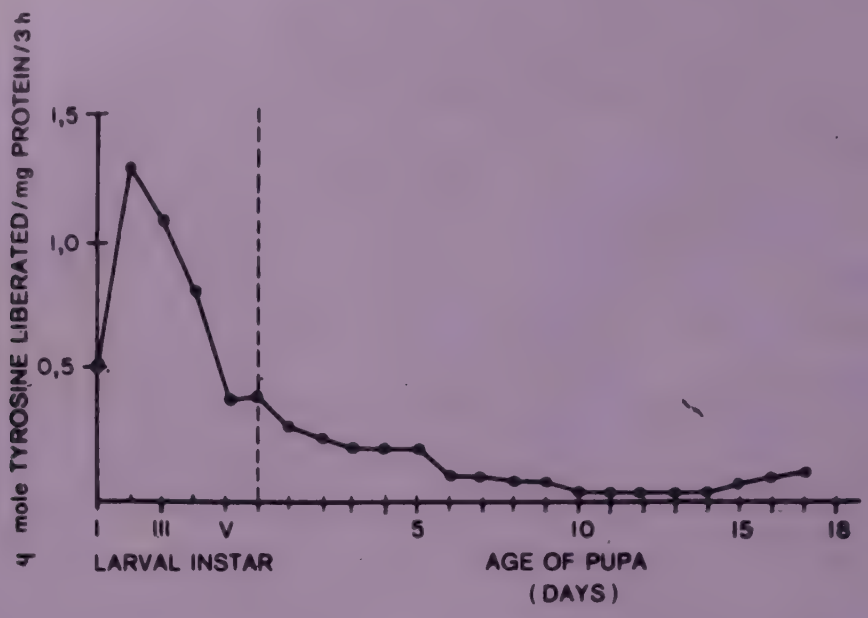


FIGURE 139. Proteolytic activity in *P. ricini* during larval-pupal development

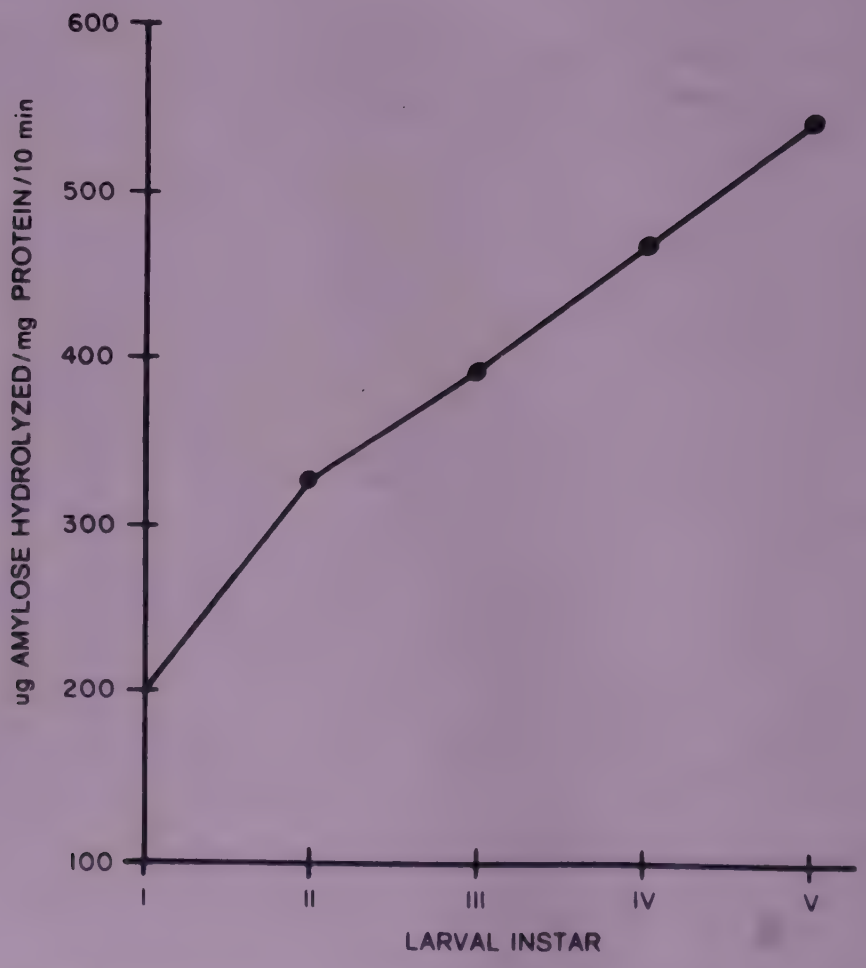


FIGURE 140. Amylolytic activity in *P. ricini* during larval development

Phosphorylase: Studies of the eri silkworm have revealed that phosphorylase decreased up to the second instar (149), thereafter remaining constant until the fifth instar (Figure 141). Conversely, glycogen steadily increases to a maximum concentration in the last instar. At the onset of pupation there is a sharp

rise in phosphorylase, followed by a drop on the first day of pupation. Instead, throughout the pupal stage, the glycogen concentration varies inversely with the activity of this enzyme.

Lipidmetabolism: There is an overall decrease in esterified fatty acids, neutral lipids and phospholipids (Figure 142) during the embryonic development of eri silkworm (147). The sterols remain at about the same level throughout embryogenesis.

The fat body of the moth exhibits sexual dimorphism as regards lipid content (152), which is higher in the male than in the female.

35.3 Composition of fibroin and sericin

The eri fibroin has a higher alanine than glycine content by a ratio of 0.6:1. Eri silk is characterized by a low sericin content of 4.96% as compared with 10% in mulberry silk, 8.62% in tasar and 7.88% in muga (36). The amino acid pattern of the sericin is almost the same as that of the fibroin, but it is characterized by less glycine and alanine and more lysine and dicarboxylic acid.

35.4 By-products

The dried or cooked pupae contain 25% oil and 50% protein. The oil is a good soap component, and the pupal powder (11% nitrogen) can be used as a poultry, piggery and fishery nutrient.

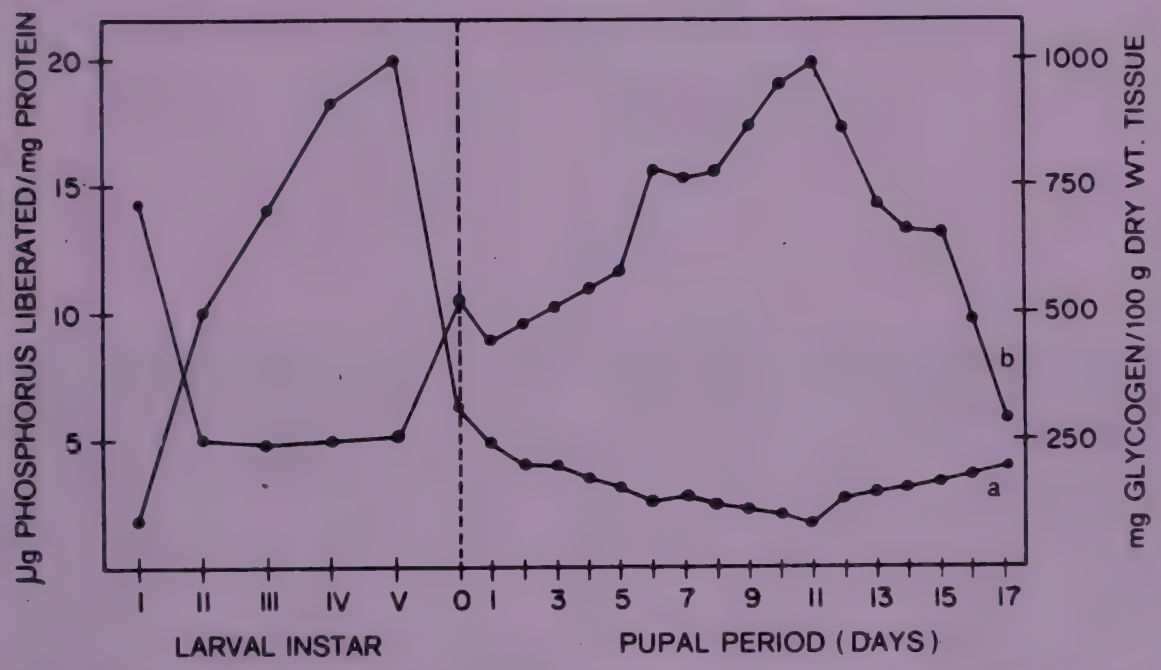


FIGURE 141. (a) Glycogen concentration and (b) phosphorylase during larval-pupal development of *P. ricini*

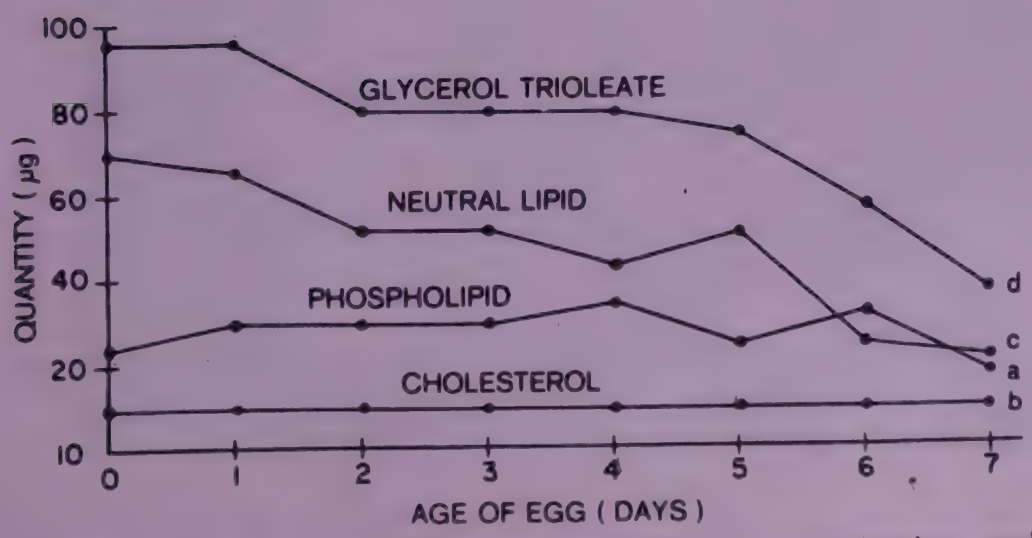


FIGURE 142. Lipid contents of *P. ricini* during embryonic development

Chapter 36

SPINNING

As has been mentioned earlier, because eri cocoons are open mouthed, the filament is discontinuous and thus can be used only for spinning. Like tasar, the cocoons vary in colour, size and softness. The soft cocoons are better for mechanical spinning, and the bigger cocoons for hand spinning. The cocoons are graded accordingly.

Despite the demerits of sun stifling (Chapter 15), it is widely practised because of its simplicity; however, hot-air drying is preferable.

36.1 Degumming

Rather than being cooked as in required for reeling, eri cocoons are degummed. The sericin (about 11%) is washed out, making the fibres loose enough to be stretched for the drafting operation (184).

Traditional methods: In Assam, ash obtained from banana leaf, wheat stalk, paddy straw, mung or pieces of green papaya is commonly used, instead of soda or potash, to degum the cocoon; however, does not completely dissolve the sericin.

The cocoons, loosely tied in cloth, are boiled in a 10% Na_2CO_3 solution for 45 minutes to an hour. The individual cocoons are then stretched or opened in plain water into thin sheets. Three or four such sheets are joined to make a "cake", which is dried (Figure 143) and used for spinning.

Improved method: Clean eri cocoons are loosely tied in a porous cloth, and the bundle is immersed in an alkaline bath of 20% soap plus 2% soda, maintaining a 1:6 ratio of liquid and cocoons. The cocoons are boiled for one hour and then washed and reboiled in fresh water for 30 minutes. The degummed

FIGURE 143. Eri cocoon cakes after degumming

cocoons are thoroughly washed twice in fresh water and squeezed for drying.

36.2 Spinning

Hand spinning: Hand spinning, which is very common in northeastern states of India, is either intermittent (mule spinning principle) or continuous (ring spinning principle). The takli is commonly used for intermittent spinning, and the spinning wheel for continuous spinning. Both types of spinning involve the same basic operations: drafting, twisting and winding.

Takli spinning: The takli consists of a spindle with disklike base (Figure 144). The spinner holds the cocoon "Cake" in the left hand, drafts and then feeds the strand with the right hand to the spindle. The spindle is occasionally rotated by the right hand to impart twist. After a certain length of yarn is spun, the spinning is discontinued in order to wind the yarn on the spindle.

Improved spinning appliance: Although the takli is very simple and cheap, its output is quite low. Improved spinning equipment has been developed on the continuous spinning principle with simultaneous drafting, twisting and winding.

The N.R. Das spinning wheel is pedal driven and has a flyer system. A large pedal wheel drives the top step wheel, which, in turn, drives the double-flanged bobbin. The spindle and flyer are mounted horizontally on a wooden platform with an automatic traverse motion (Figure 145). Continuous rotation of the bobbin gives the yarn a uniform twist and simultaneously ensures uniform distribution of the yarn coils as they are wound on the bobbin. Both drafting and feeding of the fibres can easily be controlled.

The Trivedi and Chowdhury spinning wheels (Chapter 15) are also popular for eri spinning. The production on these machines is 25–30 g per day for 20s (metric cotton count) yarn (185).

36.3 Important properties of eri silk

Eri silk is white or brick red and less lustrous than other silks. It is 2.2–2.5 denier, with a tenacity and an elongation of 3–3.5 g/d and 20–22%, respectively. The ash (2.2%) and vegetable fibre (43%) contents are higher than in mulberry silk. Eri spun yarn shrinks considerably after washing and has a greater tendency toward yellowing. Because of eri's poor affinity for dyes, it is generally blended with wool.

FIGURE 144. Takli for spinning eri cocoons

FIGURE 145. N.R. Das spinning wheel

36.4 Spun silk mill

A large quantity of eri cocoons and of tasar and muga silk waste are mechanically spun in a silk mill. The various processes (23) are described in the following paragraphs.

Degumming: The reeling and thread waste is boiled in an open vat containing soap and soda for one to two hours, depending on the quality of the material. Two such baths give better results. Eri cocoons and cocoon waste, can also be degummed in Kier pressurized boilers. After degumming the material is washed in fresh water, which is then removed with a hydroextractor, and subsequently dried in hot-air chambers. After drying it is stocked in the conditioning room for about a week to reabsorb moisture. The different qualities of waste are blended for economy and quality.

Opening The degummed material is processed in the opener, which converts the tangled mass of fibre into a thin lap of more or less parallel filaments.

Filling or pegging: The lap is transferred to the drum of a filling or pegging machine with rows of combs on the surface. After this treatment the strips are cut and removed section-by-section with special wooden sticks.

Dressing or combing: The fibres in the strips are of varying length and not perfectly parallel. To obtain homogeneous slivers the fibres are separated by length and all impurities removed on as many as four circular dressing machines. The combs on each successive machine are more closely spaced. From the final combing "exhaust noil" used for making bourrette yarn is obtained.

Drawing folder or spreader The combed slivers, or drafts, are then integrated into a continuous ribbon of stretched fibres on a drawing folder or spreader. The lap is passed two or three times over the same or different spreaders to make it more even and the fibres more parallel.

Drawing frame: The slivers are doubled and passed through a machine called a drawing frame. The drawing is repeated on three more heads to attain a high degree of evenness and fibre parallelization in the sliver, which is almost twistless.

Gill roving frame: Slivers from the final drawing head are drafted six to eight times in this frame to convert them into slubber or into roving which is slightly twisted.

Spinning. The rovings are spun on the ring spinning frame into very fine yarns in the range of 60–210s (metric counts). Here the roving is again drafted to the degree of 20–25 through a series of fluted and plain rollers on the principle of worsted spinning, and sufficient twist is imparted to the spun yarn. The single spun yarn from the ring spinning frame is then doubled in a doubling frame and twisted in a ring twisting frame.

Gassing: The yarn is passed through a gas flame at sufficient speed to burn off the hairy fibres. The gassed yarn is sometimes cleaned to brighten the colour as gassing causes dullness. The singed thread is then passed between rotating steel rollers to remove the burnt fibres adhering to it.

Reeling: Finally, the spun silk is cross-reeled on a reeling frame to make standard hanks. The hanks are dressed, folded and packed in bundles, which are presspacked into bales for market.

36.5 Noil spinning

The short fibres deposited during the dressing process are not long enough to be drafted for spinning into fine yarn. They are used, rather, to produce a coarse yarn known as noil yarn. The short fibres (noils) are first opened in a waste opener and then fed to a breaker card, which yields a lap at the other end. The laps are fed to a tape condenser card, from which they emerge as rovings. The rovings are spun into noil yarn on a ring spinning frame in the range of 7–22s (metric count). The noil yarn is also processed on a reeling machine into standard hanks.

Part VI

ANAPHE

Chapter 37

ANAPHE CULTURE

The chief source of silk in southern and central Africa are wild silk moths of the genus *Anaphe* of the family Notodontidae. Anaphe silk is commonly used for fabric and for embroidery works which are highly valued by the native population. The anaphe silkworms grow in a wild state, and unlike all other economically exploited silkworm varieties, they form the cocoons communally.

37.1 Anaphe fauna

The *Anaphe* species are widely distributed in the intertropical regions of continental Africa (Nigeria, Uganda, Cameroon, the Congo, Togo, etc.). The important species used in the production of anaphe silk are *A. infracta* Walsingham, *A. venata* Butler, *A. panda* Boisduval, *A. reticulata* Walker, *A. carteri* Walsingham, *A. moloneyi* Druce and *A. ambrizia* Butler. The closely related species *Epanaphe carteri* Walsingham and Epanaphe (Hypsoides) vuilleti Joan are exploited in Cameroon.

37.2 Food plants

The *Anaphe* are polyphagous. Of the twenty-two food plants thus far recorded, *Albizzia fastigiata, Sterculia tragacantha, S. setigera, S. rhinopetala, S. oblonga, Cordia milleni, Tamarindus indiicus* and *Zizyphus mucronata* are found in Nigeria; *Bridelia micrantha, Cynometra alexandri* and *Triumfetta macrophylla* in Uganda; and *Z. jujuba* and *A. fastigiata* in Cameroon and the Congo. *C. milleni* and *B. micrantha* are the preferred food plants of *A. moloneyi* and of *A. infracta* and *A. venata,* respectively.

Because in nature the food plants are scattered over a large area, systematic rearing is almost impracticable. To overcome this problem, the plants should be raised in a compact area, thereby increasing the population density and the leaf yield. *B. micrantha,* which flourishes in virtually all climatic conditions with very little attention, can be exploited for this purpose. It can be raised from seed or seedlings or, better, from cuttings, which propagate very rapidly and are ready for use as food plants in about a year.

37.3 Morphology

The freshly laid eggs are soft and creamy white, but later become hard and grey. They are discoidal and isodiametric, measuring 0.97 x 0.62 mm.

The larva is green. The antennae and thoracic legs are little developed. Pairs of tubercles present on the thoracic and abdominal segments bear short brown setae. Long tufts of white hairs are dispersed over the body. Like ***Antheraea***, the pupae are obtect adectious type and dark brown.

The wings of the moth are creamy white with a span of 4–6 cm. The fore wing has two broad bands in the middle joining at the posterior margin to form a V and two subparallel bands from the outer arm of the V to the lateral margin. The lateral margins of both fore and hind wings are bordered with dark brown bands, less pronounced in the hind wings. The abdominal segments are marked with rings of golden brown hairs. The posterior extremity of the body of the female is covered with golden brown hairs.

37.4 Cultural operations

The anaphe silkworm is univoltine (5, 46) and undergoes diapause at the pupal stage. There are two overlapping broods of the insect, each with a one-year life cycle. The moths of one brood emerge in September, and those of the other in January. The most striking difference between the two broods is the length of the pupal stage, which is about thirteen weeks in the September brood, but only six weeks in the January brood (5). The silkworm grows in a wild state. The cocoons are collected by the natives and spun into yarn.

Emergence: The emergence commences at dusk and in the early evening, usually from early in January to early in March (50). Maximum emergence has been observed during the first eight to ten days of February.

The emerging adults push through the conical projection of the cocoon mass.

Before emergence they secrete a colourless fluid which helps moisten the exit channel. The adult propels itself out of the cocoon by wriggling the abdomen. It then crawls onto the communal cocoons or onto the substrate to which the cocoon is attached. An adult lives for nearly a week. The ratio of male to female moths is 3:2.

Coupling: Coupling starts soon after emergence and may last 5 to 24 hours. The male moth flutters its wings and approaches the female, which raises its abdominal extremity. As as soon as they decouple, the female starts laying eggs (9).

Egg laying: The female clings tightly to the underside of the leaf of the food plant and starts rubbing the tip of the abdomen to construct a covering layer by means of the golden brown hairs on its abdominal extremity. The eggs are then laid in clusters of 250–350. The egg laying continues for 8 to 20 hours.

Hatching and larval feeding: The embryonic period may last for a month or more (45 days), depending upon the climatic conditions. The average hatching rate is about 90%. The newly hatched larvae are gregarious. They remain on the underside of the leaves and eat so voraciously that they almost denude the food plant. The larvae dislike sunlight and do not migrate unless there is a shortage of leaves. The total larval period is about 140 days. A single larva consumes nearly 20–25 g of foliage from hatching to maturity. Toward the end of larval period they establish themselves on the bifurcation of branches for cocooning. The cardinal points in anaphe silkworm rearing are sufficient food, ample shade and minimum disturbance (46).

Cocooning: With the initiation of cocooning the larvae start spinning a hammock without leaf support by throwing out silk in every direction. The silkworms collectively spin a large nestlike cocoon (Figure 146), usually ferruginous brown and 10–15 cm long, 10–21 cm wide and 5–12 cm thick. The size

FIGURE 146. An *Anaphe* cocoon nest

varies, however, with the number of silkworms involved in the formation of the nest — most frequently from one dozen to several hundred. At times the number may exceed a thousand and a live cocoon mass can weigh up to 3.5 kg. The cocoon formation is completed in 3 to 4 months.

Harvesting and preservation : The nests are harvested by cutting the branches at 5 cm from either side. The selected seed cocoons are kept suspended in garlands in adequately ventilated, clean rooms.

37.5. Diseases and pests

The loss due to diseases is negligible. The silkworm has been reported to suffer only from muscardine (160). It is vulnerable, however, to many parasites and predators. The egg is parasitized by two chalcids, *Telenomis gowaeyi* and *Pleurotropis telenomis*, and the silkworms are attacked by the tachinid fly *Exorista cardinalis* and the *ichneumon* fly *Cryptus leucopygus*. These two paraisties of the larval stage are responsible for a 30–35% crop damage. Among the predators, birds cause considerable losses.

37.6. Fibre technology

Being communal, anaphe cocoons are unreelable and can only be spun. Hence, they are not stifled. The cocoon nest has three layers: 1) an outer fibrous mass, 2) an inner hard shell and 3) the individual cocoons. The silk obtained from the individual cocoon layer is superior to that of the shell (117).

The cocoons are cooked either in wood ash for about two hours or in sodium carbonate (3%) for about one hour. Cooking in a higher concentration of Na_2CO_3 or HCL causes disintegration of the fibres due to over degumming, whereas cooking in water does not render the cocoons suitable for spinning because of incomplete degumming. The degummed cocoons are spun on a spindle or bobbin like cotton. The silk percentage is 62.2% (10).

Anaphe silk more closely resembles mulberry silk. The filament is very fine, circular in cross section and on average measures 18 microns in diameter; however, the striations are more prominent than in mulberry. The elongation of the fibre is less than in mulberry silk, but higher than in other silks. The spun silk is brown, but it can easily be bleached with oxidizing agents.

37.7. Economics of anaphe culture

One hectar of systematic plantation can accommodate about 2 200 plants with 3.0 x 1.5 m spacing with a possible yield of 25–27 metric tons of leaves. This is enough to sustain 6 500 – 7 000 layings to produce 700–800 kg of cocoons, equivalent to 140–160 kg of unprocessed silk.

000 ×24 24 [illegible]

28 ○ π ○ 1 ○ 2

7

100

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